GILBERT

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HYDRAULIC & PNEUMATIC ENGINEERING

GILBERT
Hydraulic and Pneumatic Engineering

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Under the Direction of
ALFRED C. GILBERT
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INTRODUCTION

NOWADAYS there are so many very interesting things going on all about us that very often we are likely to overlook things which have an important bearing on our everyday life. Small things which we are so used to having around that we never stop to think what they really mean to us.

For instance water. It's nice to drink, and bathe in but very few of us ever stop to consider the innumerable uses water is put to and what a great influence it has on many things we do. Most of us are satisfied to turn on the faucet and get our water in that way. If something is wrong and the water doesn't come from the faucet we call up the plumber, but we do not realize what has gone wrong simply because we do not understand how a house is piped for water nor do we understand why water gets into the pipes, etc.

Then air — another thing which we couldn't live without and yet few appreciate its value. Air and water give us tremendous results as pneumatic and hydraulic pressure. A knowledge of these great forces which most boys are so familiar with and still do not understand thoroughly will put you up far ahead of your boy friends. Most boys take things too much for granted; it is the clever boy who digs into things and find out the reasons.

It is the earnest hope of the authors of this book that the boys who read it will have a better understanding of water and air, how they are used, and what they mean to us.

Sincerely yours,

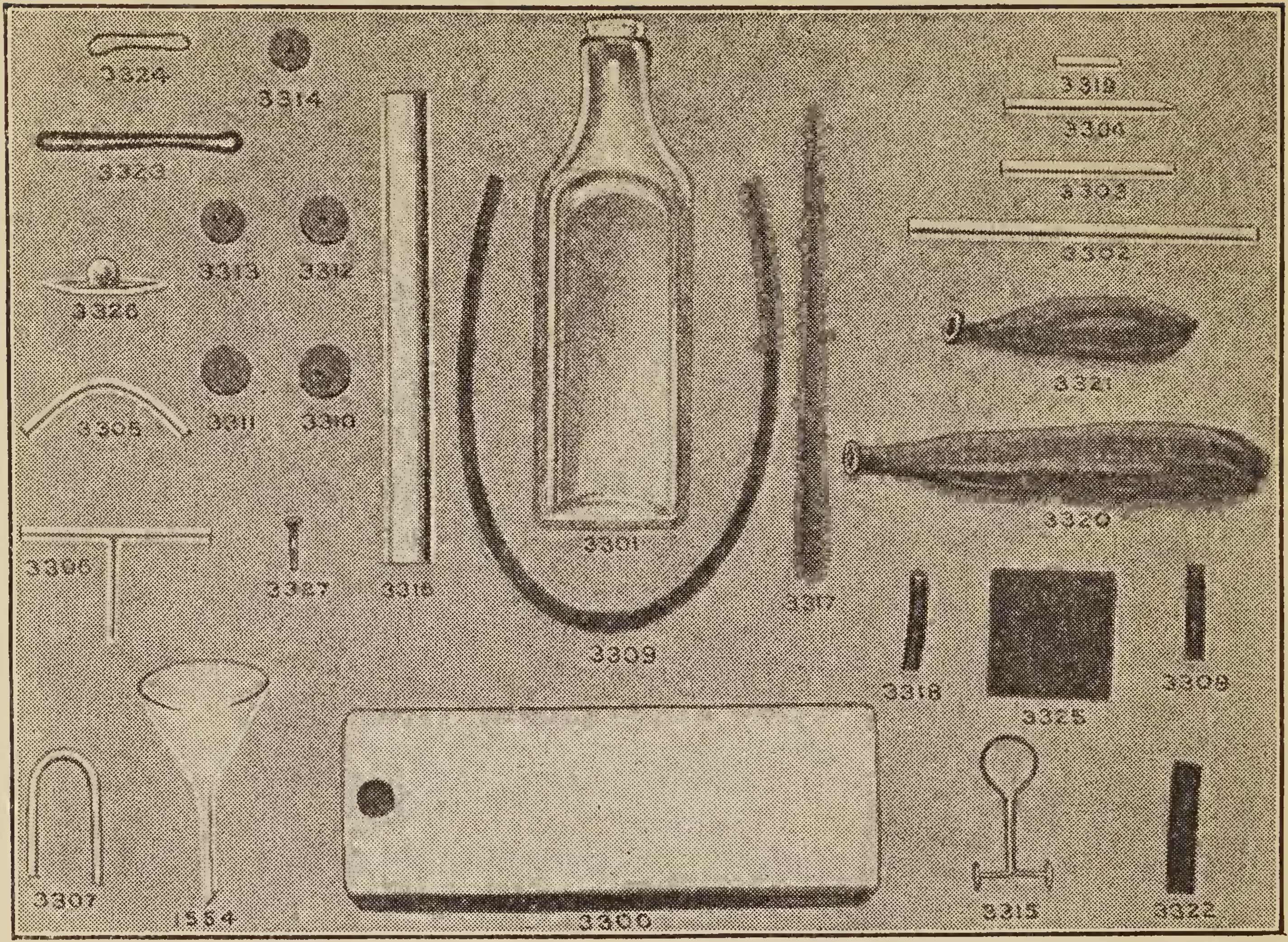
A. C. Gilbert

INDEX TO ILLUSTRATIONS

HYDRAULIC APPLIANCES

PNEUMATIC APPLIANCES

CHART OF HYDRAULIC AND PNEUMATIC SEPARATE PARTS



No.	NAME	DESCRIPTION
3300	TIN TANK	7 7/8″ x 2 7/8″ x 1 7/8″
3301	BOTTLE	7 1/2″ High, Base, 2 1/2″ x 1 1/2″
3302	GLASS TUBE, Long	5 1/2″ x 7/32″ diameter
3303	GLASS TUBE, Short	2 3/4″ x 7/32″ “
3304	GLASS NOZZLE	2 3/4″ x 7/32″ “
3305	GLASS TUBE ELBOW	2 3/4″ Long, 7/32″ diameter
3306	GLASS TUBE TEE	3″ 7/32″ “
3307	GLASS TUBE “U”	3″ 7/32″ “
3308	RUBBER COUPLING	1 1/2″ x 1/4″ “
3309	RUBBER HOSE	16″ x 1/4″ “
3310	RUBBER STOPPER, Laboratory Style No.	2 two hole 3/16″ diameter
3311	RUBBER STOPPER, Laboratory Style No.	1 Solid
3312	RUBBER STOPPER, Laboratory Style No.	1 one hole 1/8″ diameter
3313	RUBBER STOPPER, Laboratory Style No.	0 two hole 1/8″ “
3314	RUBBER STOPPER, Laboratory Style No.	0 one hole 1/8″ “
3315	CLIPS, Metal, with fastener	
3316	LARGE GLASS TUBE	7″ .805″ diameter
3317	WOOD HANDLES	7″ tapered 3/8″
3318	RUBBER VALVES	1 1/2″ x 1/4″
3319	GLASS VALVES NIPPLE	1″ x 7/32″
3320	BALLOON, Dirigible Type	
3321	BALLOON, Observation Type	
3322	RUBBER COUPLING, Large	2″ x 1/2″
3323	RUBBER BANDS	3 1/2″ x 1/8″
3324	RUBBER BANDS	1 3/4″ x 1/16″
3325	SHEET RUBBER PIECE (White)	2″ x 1 1/2″
3326	SUBMARINE	1 3/4″ diam. diam.
1554	GLASS FUNNEL	4 1/2″ long, top 2½″ “ bot. ½″ “

THE A. C. GILBERT CO., NEW HAVEN, CONN., U.S.A.

In Canada; The A. C. Gilbert - Menzies Co., Limited, Toronto, Ontario.

Hydraulic and Pneumatic Engineering

Hydraulic Engineering is the Engineering which deals with water and other liquids.

Pneumatic Engineering is the Engineering which deals with air and other gases.

WATER SUPPLY

Boys, have you running water in your homes? If so, do you know how it gets there? You will show how with this Engineering set.

If you live in a city, your running water is supplied in one of three ways: first, it is pumped into a standpipe or reservoir; second, it is brought from a distant lake or stream at a higher level; or third, it is pumped directly into the city mains.

The standpipe method is illustrated in Fig. 1. The water is pumped by means of a force pump B from a river or lake A into a standpipe C, from which it runs by gravity through the under-ground pipes or mains to the houses D, fountains E and hydrants F. This system is used in towns and small cities situated in a flat region, because it is the cheapest means of getting the water above the level of the highest house faucet in the town.

If the town is situated near a hill, the usual practice is to build a large cement lined reservoir on the hill and to pump the water into this instead of into a standpipe. In either case the water runs by gravity through the mains and submains to the houses, hydrants, etc.

If the city is very large, the usual practice is to bring the water from a lake or stream at a higher level. New York is supplied with water in this way.

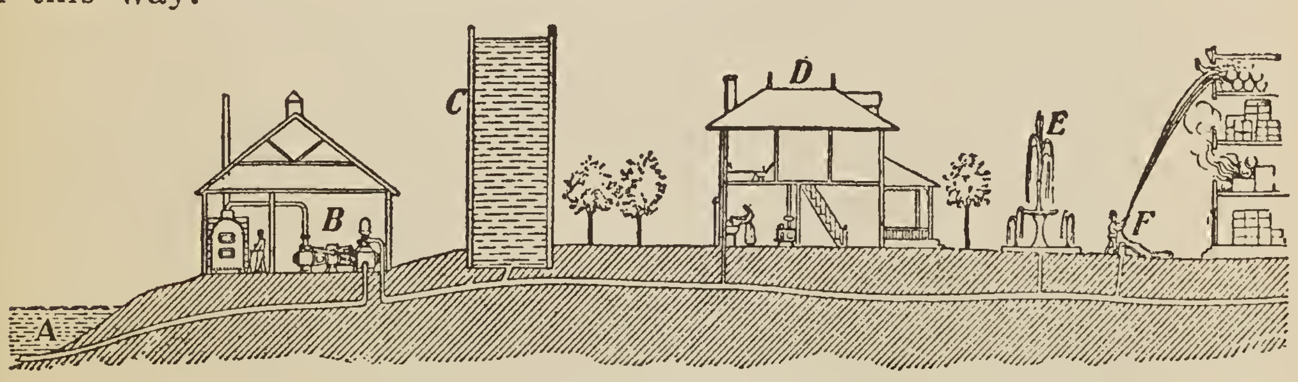


Fig. 1.—(A) Source of Water Supply (B) Pumping Station (C) Stand Pipe (D) House Supplied with Water (E) Fountain (F) Hydrant for Fire Hose.
From the "Ontario High School Physics", By Permission of the Publishers

See page 145 for diagram of apparatus needed to perform experiments in this book.

If the city is very large and if an elevated lake or stream cannot be found within a reasonable distance, the usual practice is to pump the water directly into the city mains, from the nearest river or lake.

In all cases the greatest care is taken to see that the water is pure. The land bordering the elevated lake or stream is kept free from all sources of contamination and in addition the water is filtered. If the water is pumped from a lake, the intake pipe is run out into the lake for a long distance to get the purest water and in addition the water is filtered. If the water is pumped from a river near the city, it is taken in above the city and is filtered.

EXPERIMENT No. 1

To make and operate a city water supply system in which the water comes from a standpipe, reservoir or lake.

Arrange the apparatus as shown in Fig. 2 and bury the mains an inch or two in sand or earth if convenient. Allow the water to run from the house faucet, that is, the nozzle. Attach an elbow, hose, and nozzle to the hydrant, that is, the coupling, and allow the water to run.

You have here shown how the water runs from a standpipe, reservoir, or elevated lake, through the mains to the hydrants in the streets of a city and to the faucets in the houses.

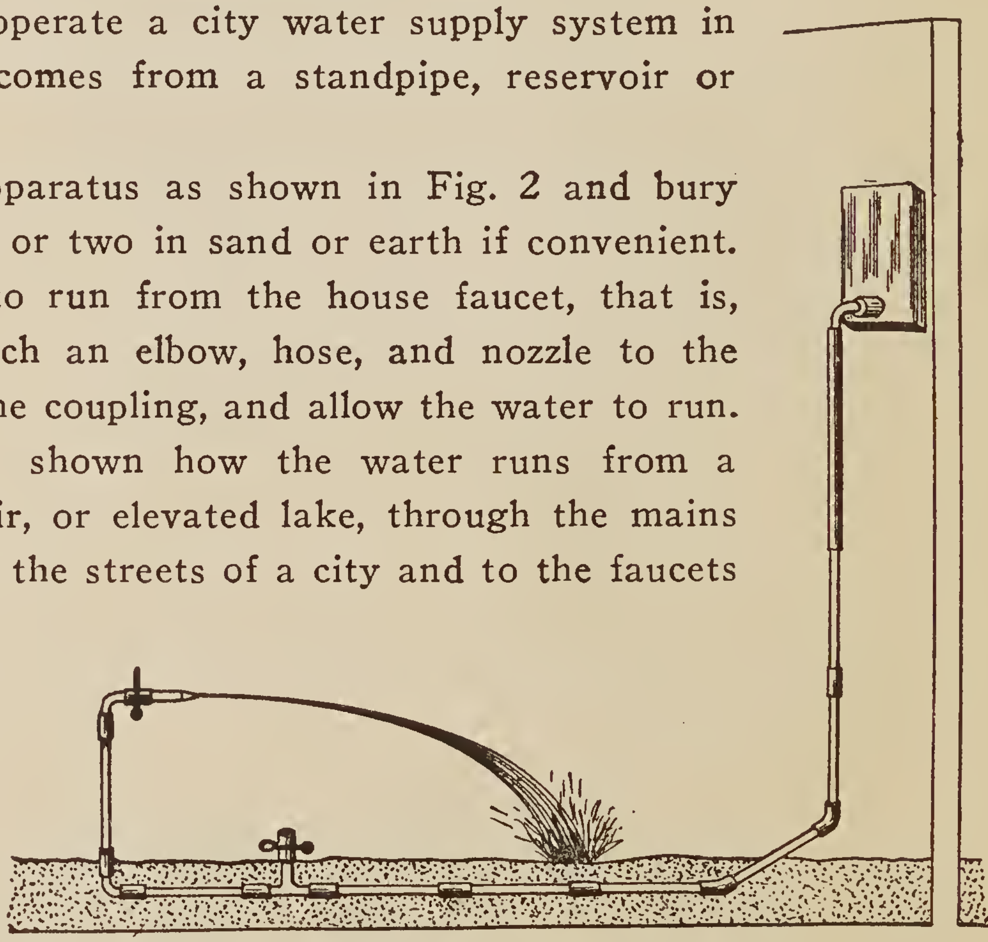


Fig. 2.—Illustrating a City Water Supply System.

NOTE 1. When you wish to insert a glass tube into a rubber stopper or coupling always place the stopper or coupling in a glass of water to wet the rubber on the inside, then insert the glass tubes with a twisting motion. Always hold the glass tube near the end you are inserting into the rubber stopper or coupling. **This is very important,** because, if you hold the tube too far back, you may break it.

NOTE 2. When you are through with an experiment always take the apparatus apart. Be sure particularly not to leave a glass tube in a rubber coupling or stopper because the tube will stretch the rubber permanently and the glass and rubber will stick together.

NOTE 3. Make the experiments out of doors, in the garage, in the basement, or in the bathroom. Keep all unused tubes in the box where you will not step on them.

NOTE 4. Let Dad enjoy this with you; he was a boy once, and will enjoy the fun as much as you do.

If you live in the country, or in a town where there is no public water supply system, and if you have running water in your home, you must have a private water supply system of some kind.

PRIVATE WATER SUPPLY

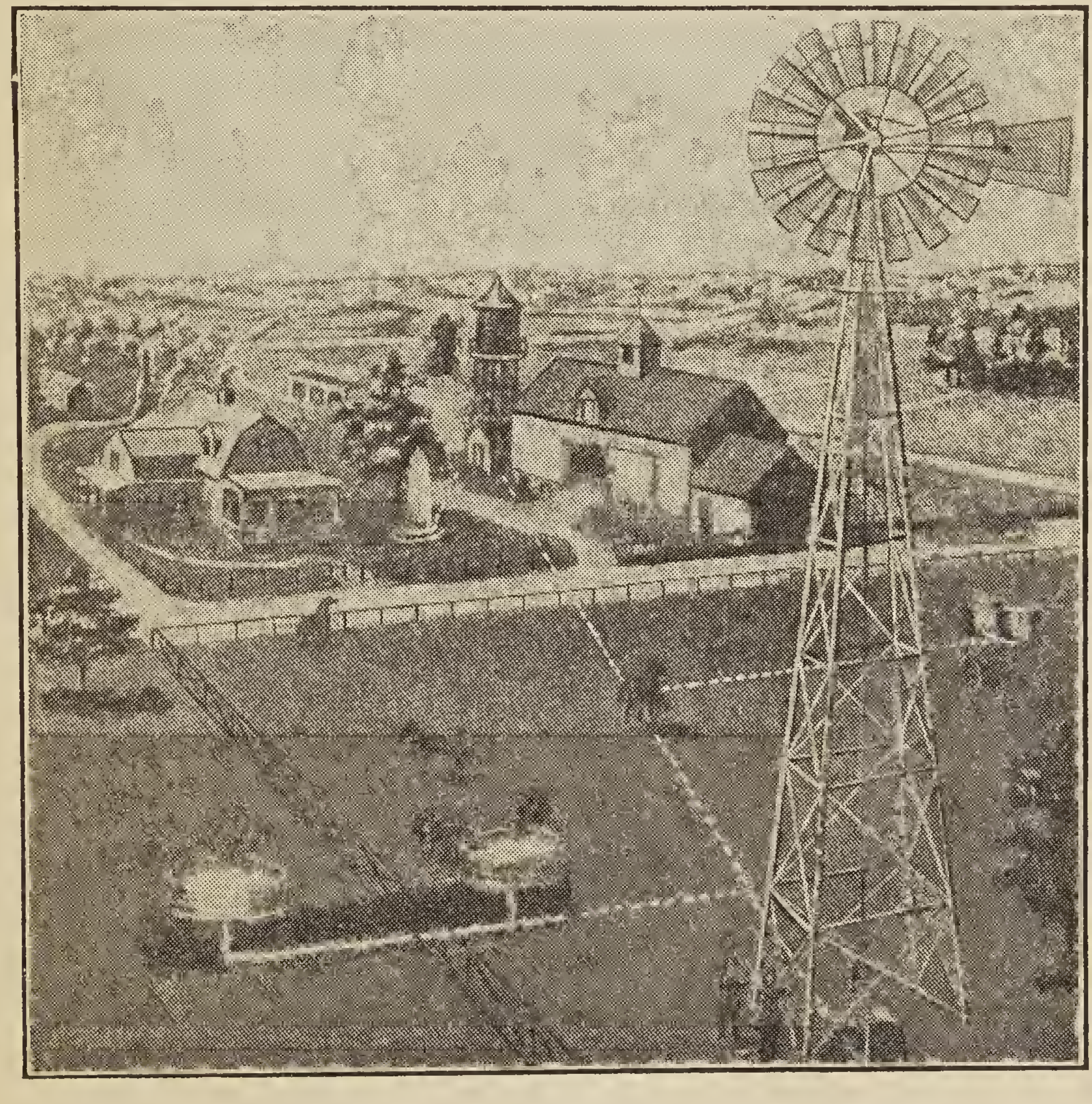


Fig. 3.—A Homestead Supplied with Running Water by Means of a Windmill and a Storage Tank on a Tower.

Courtesy of the Stover Manufacturing Company

In the system shown in Fig. 3 the water is pumped by means of a windmill and force pump into a tank on a tower and from this it runs by gravity to the house, the fountain, and the stable. The drawing in Fig. 4 shows how the water from the tank is distributed to the laundry, kitchen, and bathroom of the house.

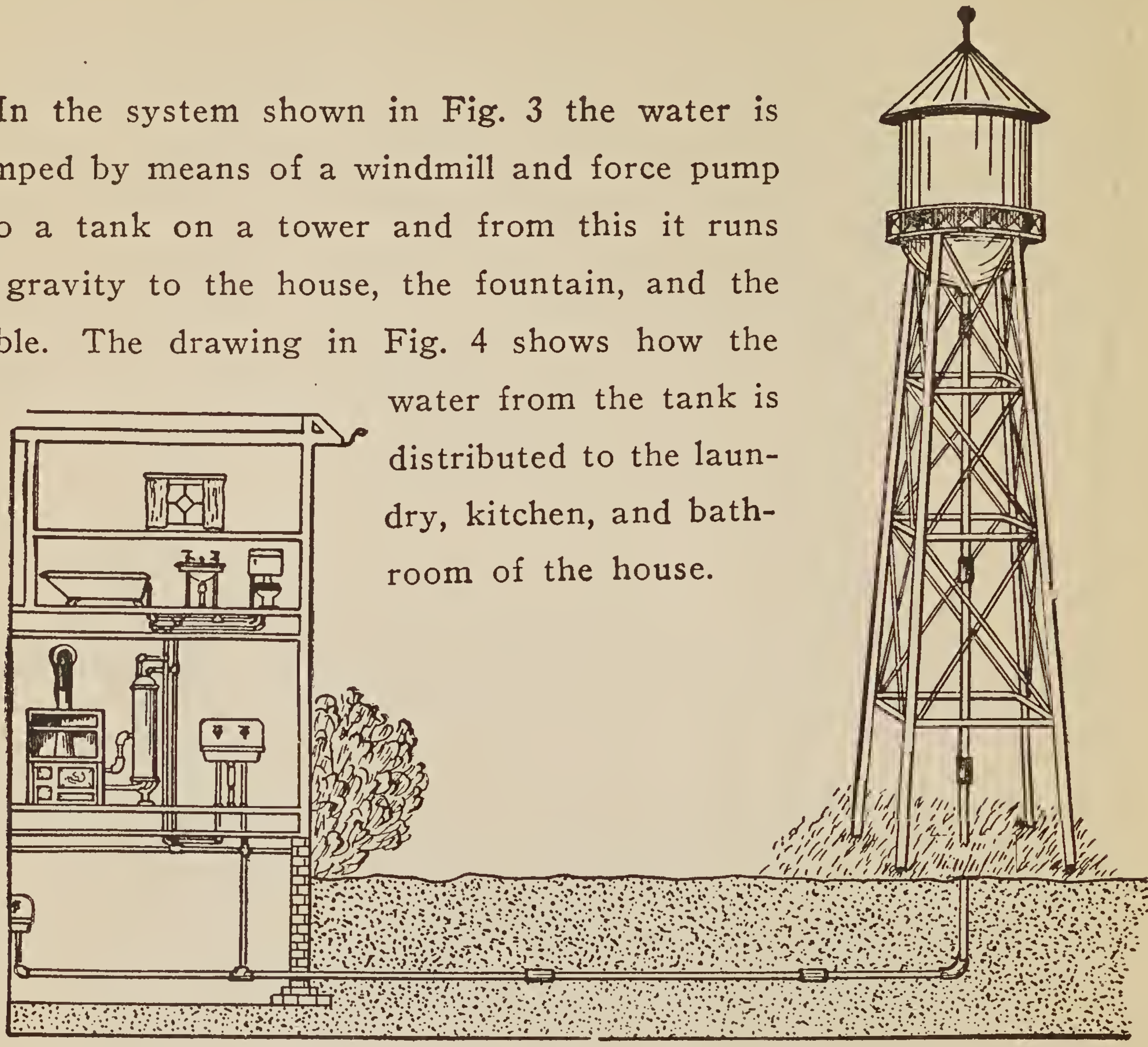


Fig. 4.—Showing How Water is Distributed in the House to the Basement Laundry, Kitchen and Bath Room.

EXPERIMENT No. 2

To make and operate a private water supply system in which the water is stored in a tank on a tower.

Arrange the apparatus as in Fig. 5. Hold the nozzles horizontal and open them one at a time, then together. Is the stream from the lower nozzle longer than that from the upper?

Arrange the apparatus as shown in Fig. 6. Open the nozzles when horizontal and at the same level. Are the streams of equal lengths?

You have shown here how the water runs from a tank on a tower through the vertical pipe and underground pipe to the faucets in the house. You have shown also that the pressure is greater at a lower faucet than at an upper faucet and that the pressures are equal at faucets on the same level.

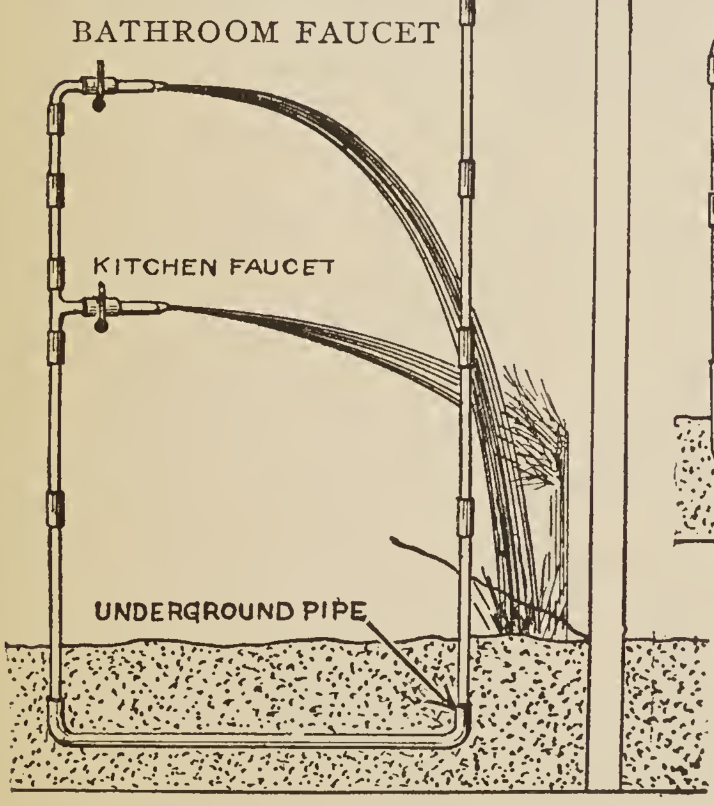


Fig. 5.—Showing How the Water Flows from an Elevated Tank to the Faucets.

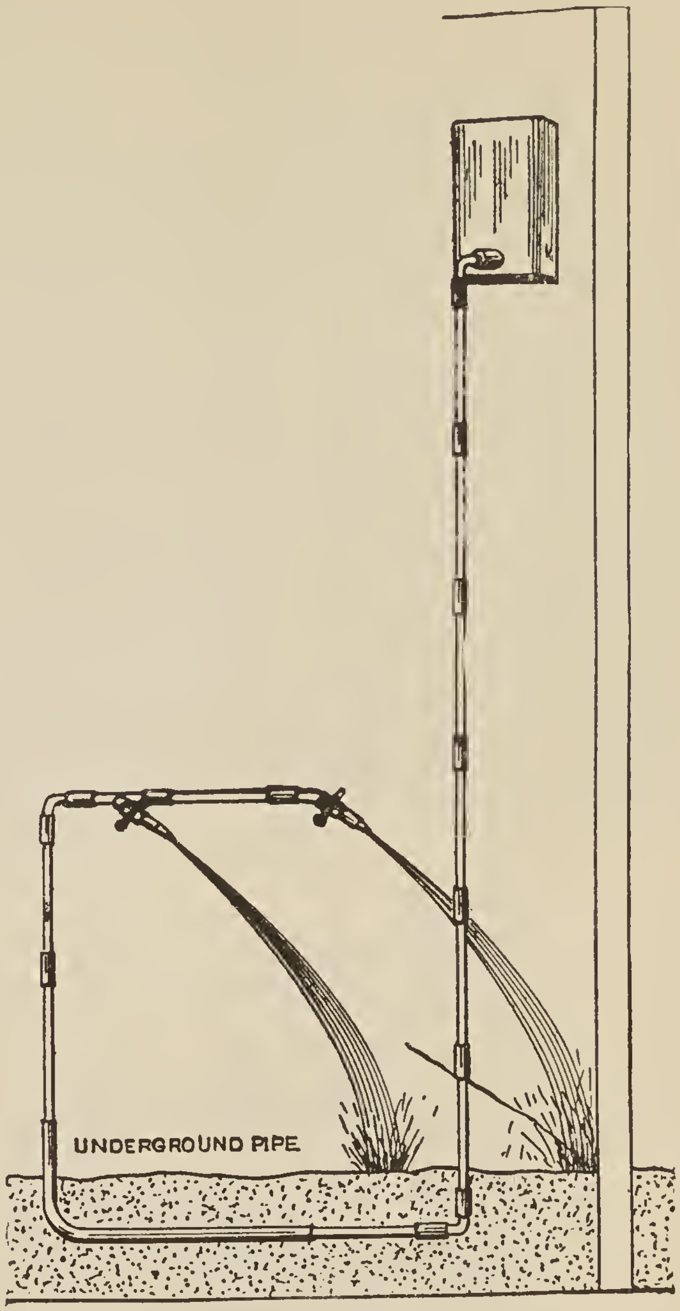


Fig. 6.—Showing that the Water Pressures are Equal at Faucets on the Same Floor.

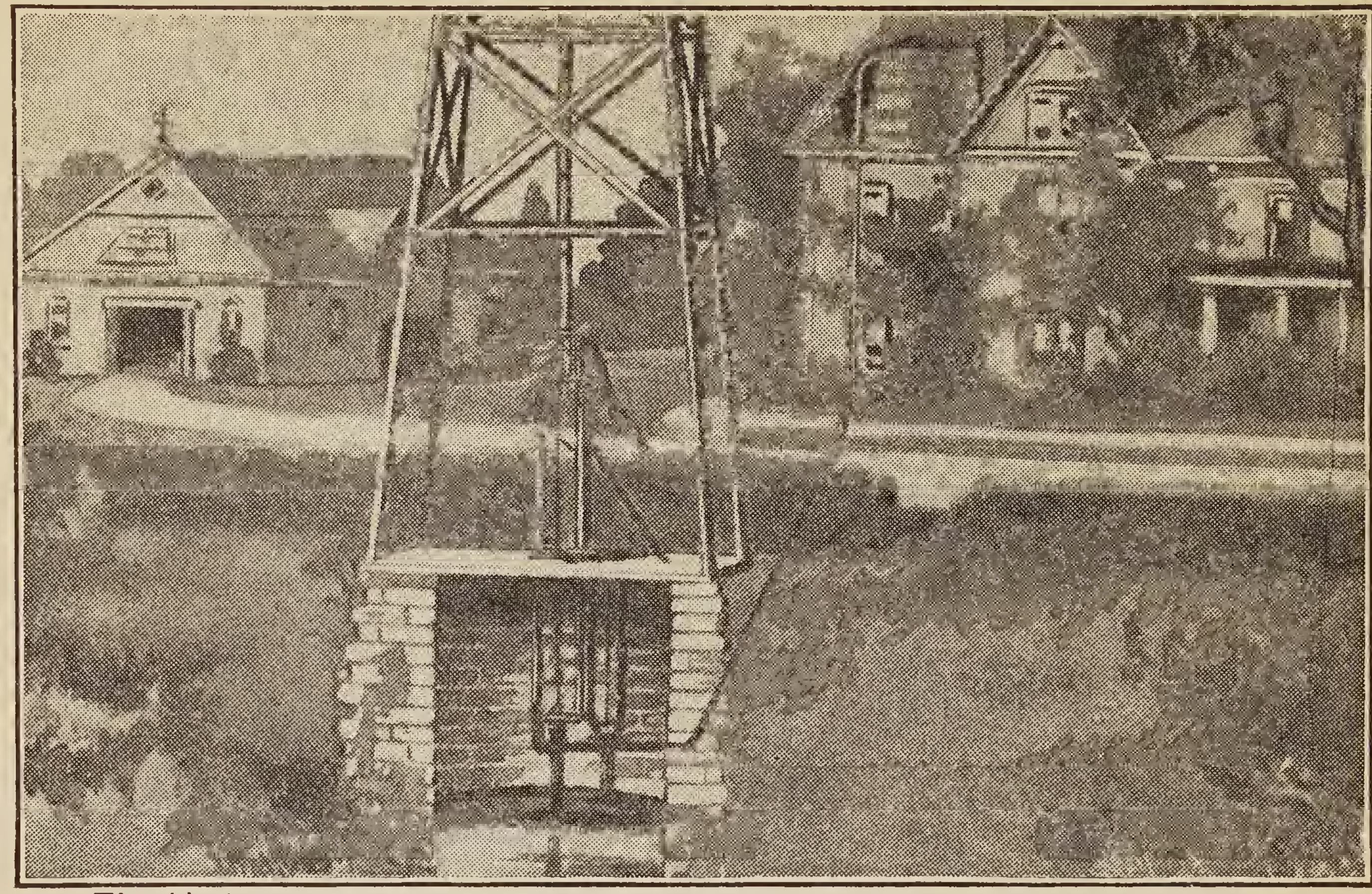
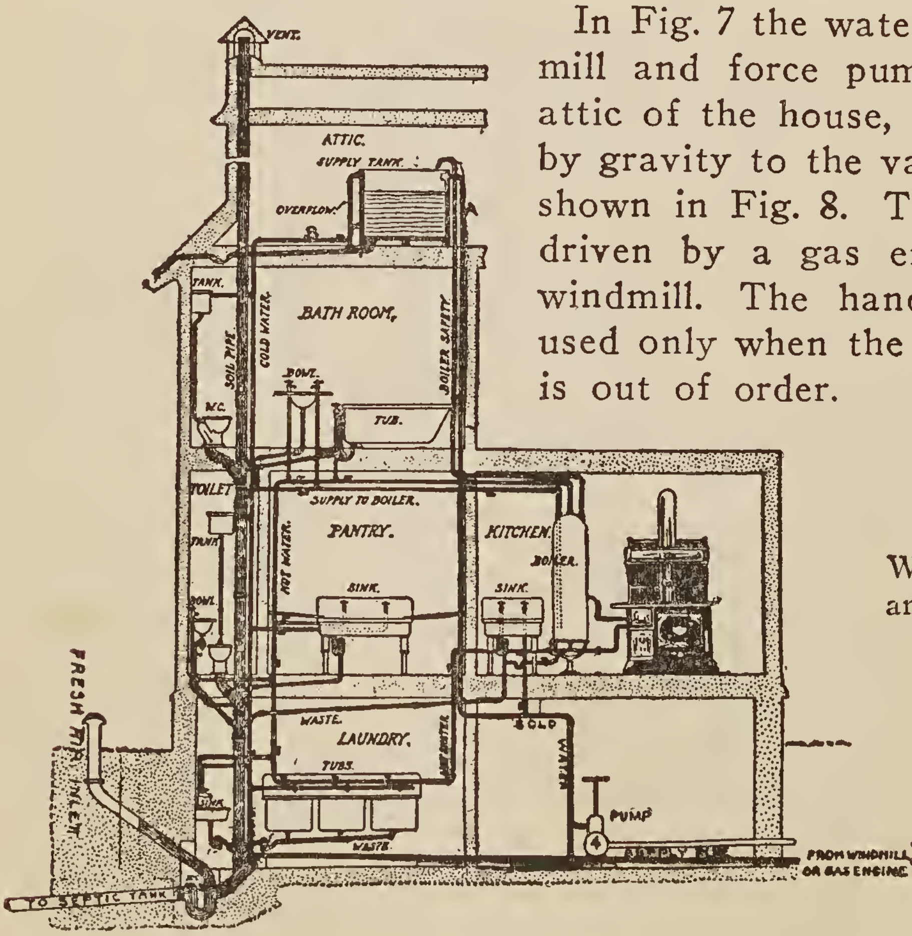


Fig. 7|—Water Supplied to an Attic Tank by Means of a Windmill and Pump
Courtesy of the Gould Manufacturing Company



In Fig. 7 the water is pumped by a windmill and force pump into a tank in the attic of the house, and from there it runs by gravity to the various house fixtures as shown in Fig. 8. The force pump is often driven by a gas engine instead of by a windmill. The hand pump (4) Fig. 8 is used only when the gas engine or windmill is out of order.

Fig. 8.—Showing How Water is Distributed from an Attic Tank.

EXPERIMENT No. 3

To make and operate a private water supply system in which the water is stored in an attic tank.

Arrange the apparatus as in Fig. 9. Hold the nozzles horizontal one above the other and open them together. Is the longer stream from the lower nozzle? That is, is the greater pressure at the lower faucet?

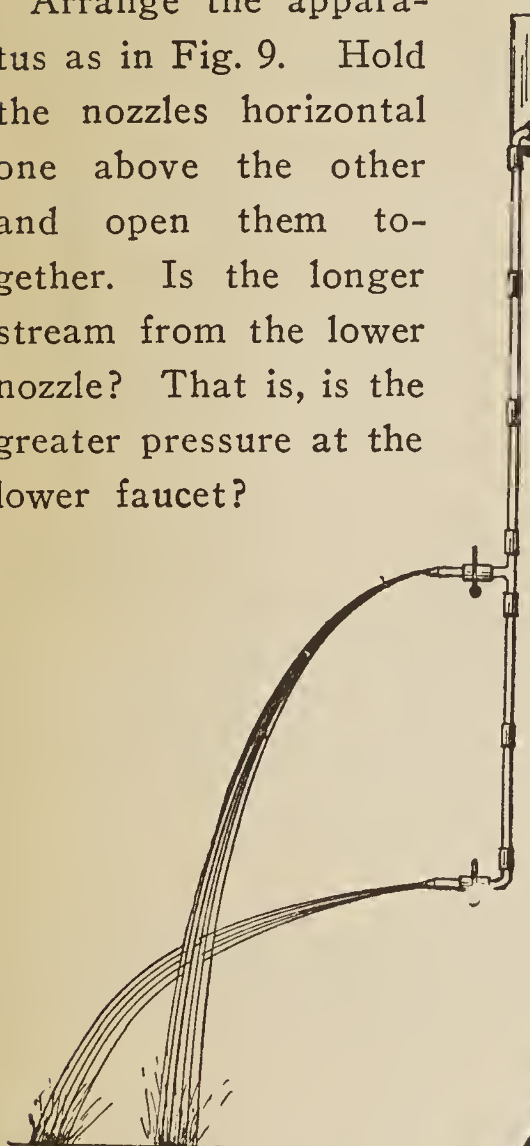


Fig. 9.—Showing How Water Flows from an Attic Tank to Faucets

Arrange the apparatus as in Fig. 10. Hold the nozzles horizontal and open them together. Are the streams of the same length? That is, are the pressures equal?

You have shown here again that the greater pressure is at the lower faucet and that the pressures are equal at faucets on the same level.

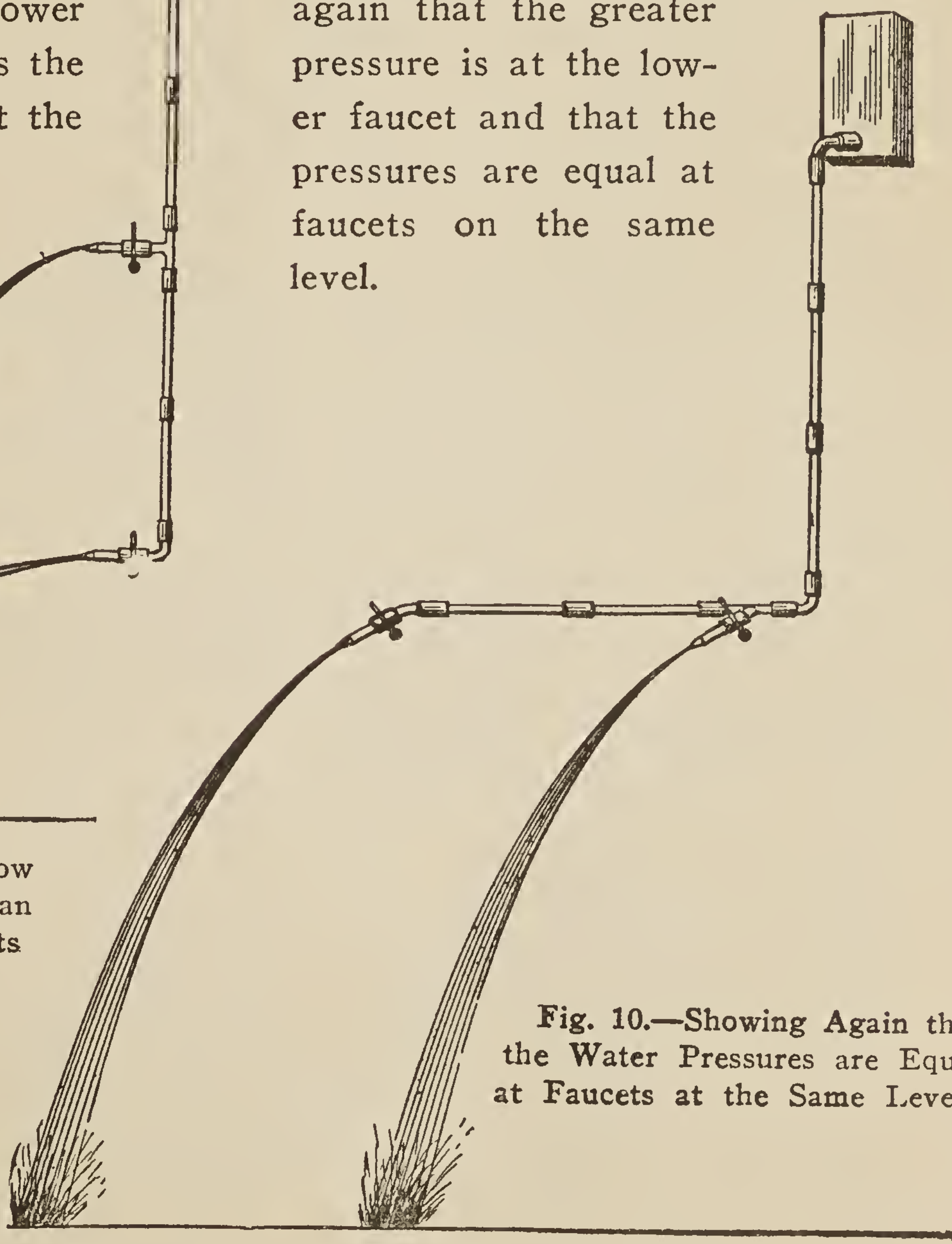
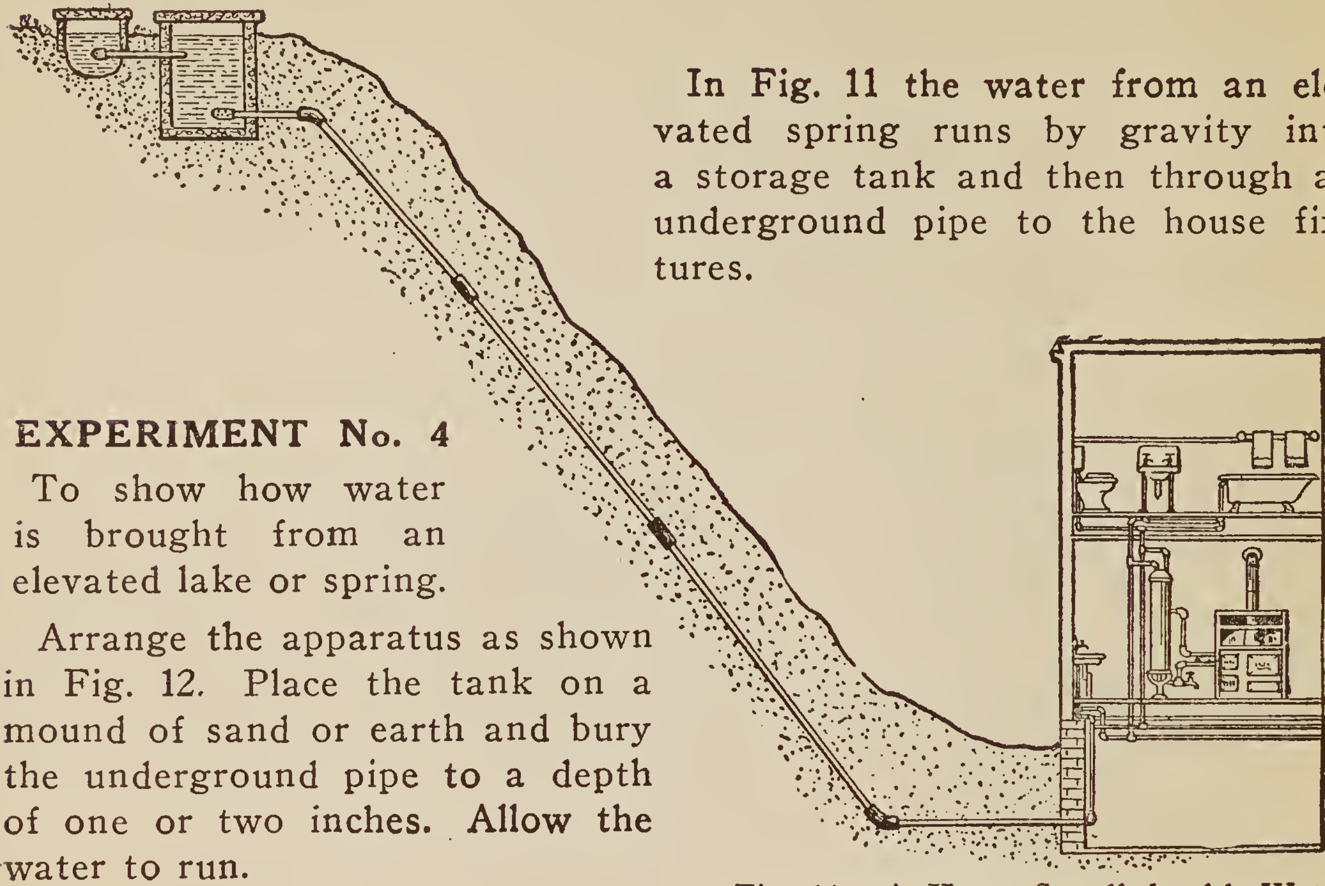


Fig. 10.—Showing Again that the Water Pressures are Equal at Faucets at the Same Level.



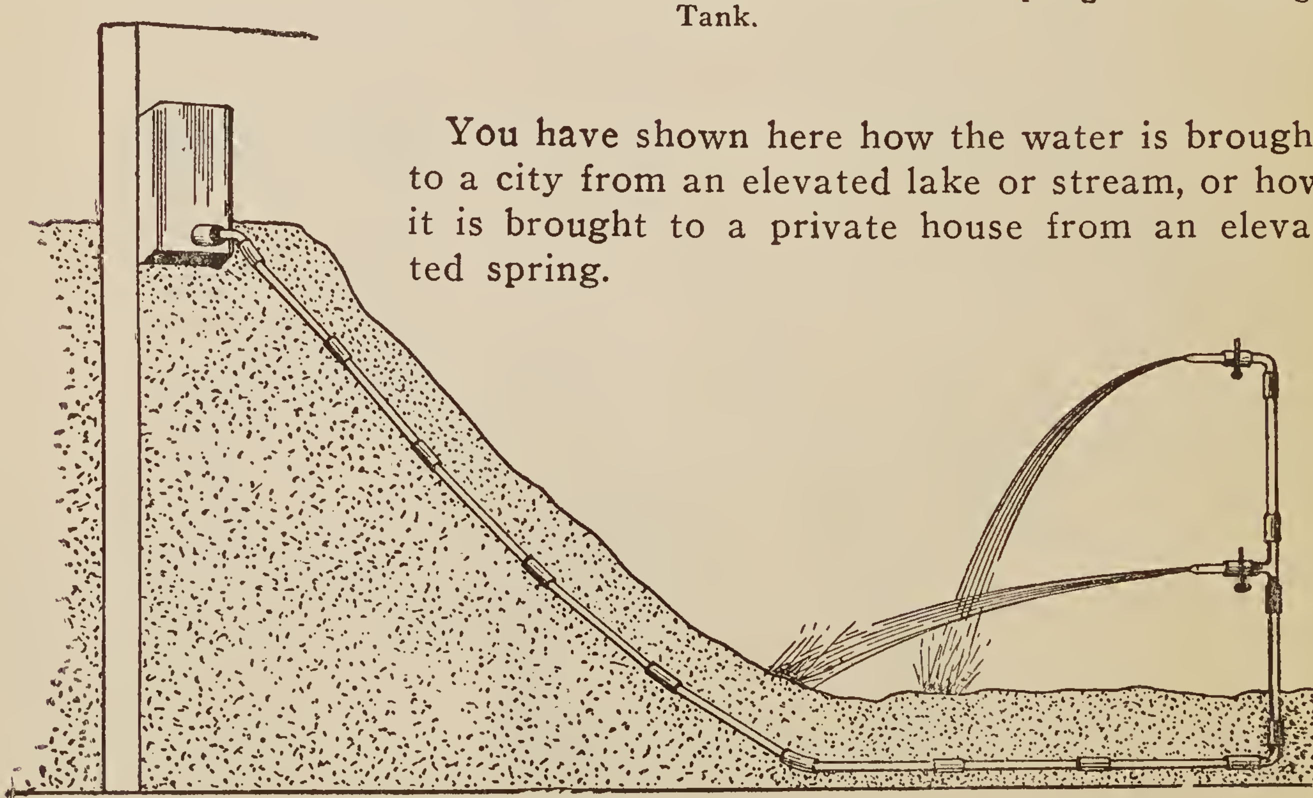
In Fig. 11 the water from an elevated spring runs by gravity into a storage tank and then through an underground pipe to the house fixtures.

Fig. 11.—A Home Supplied with Water from an Elevated Spring and Storage Tank.

EXPERIMENT No. 4

To show how water is brought from an elevated lake or spring.

Arrange the apparatus as shown in Fig. 12. Place the tank on a mound of sand or earth and bury the underground pipe to a depth of one or two inches. Allow the water to run.



You have shown here how the water is brought to a city from an elevated lake or stream, or how it is brought to a private house from an elevated spring.

Fig. 12.—Showing How Water Flows from an Elevated Spring to the Faucets

A NAVAL BATTLE

GAME No. 1

You can invent all sorts of games to be played with this Engineering set. The Naval Battle is one and it is an excellent game for a hot day.

Float a number of tin cans, tumblers, or cups on water in a bath tub, or in a wash tub, Fig. 13. Arrange the apparatus as shown. Each player directs his stream against the warships of the other, and the winner is the one who first sinks all the enemy war ships.

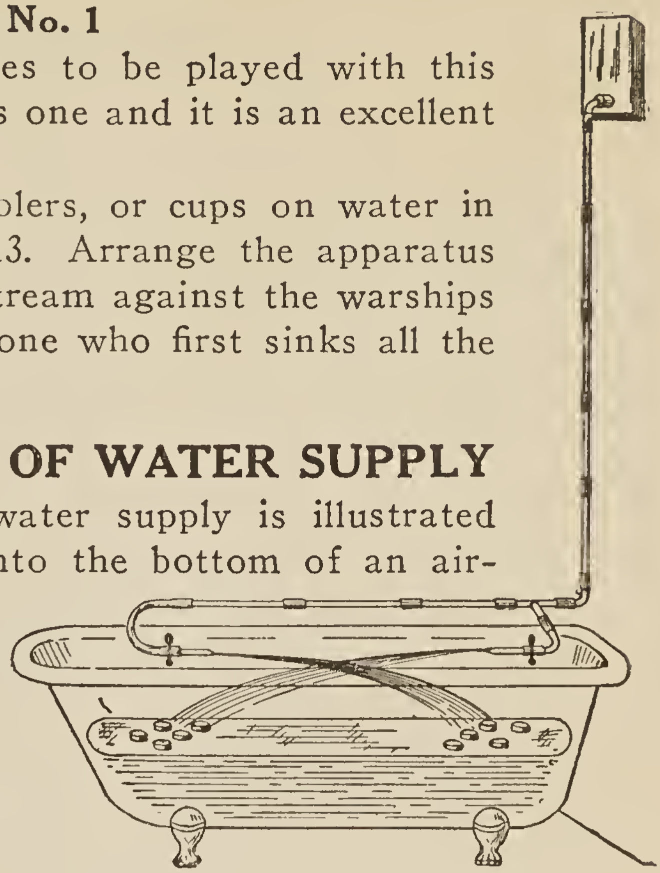


Fig. 13.—A Naval Battle.

PNEUMATIC TANK SYSTEM OF WATER SUPPLY

The pneumatic tank system of water supply is illustrated in Fig. 14. The water is pumped into the bottom of an air-tight steel tank and compresses the air in the tank to smaller volume at the top. This compressed air then forces the water out through the discharge pipe at the bottom of the tank and lifts it to the faucets in the rooms above. The interior of the tank is represented in Fig. 15. The compressed air at the top of the tank forces water up the discharge pipe when any faucet C is opened.

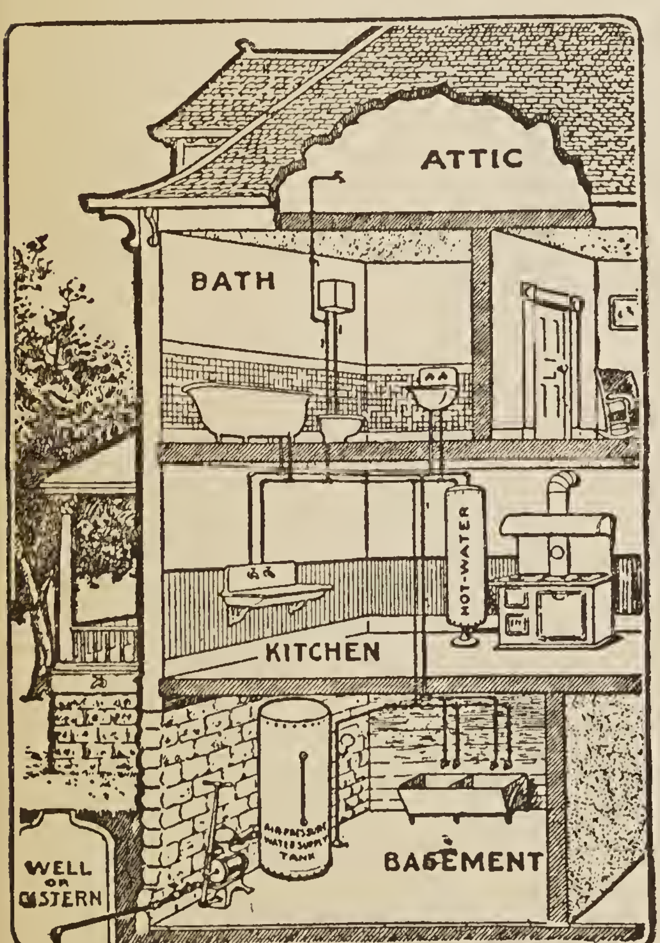


Fig. 14.—A House Supplied with Water by Means of a Pneumatic Tank.
Courtesy of The Andrews Heating Co.

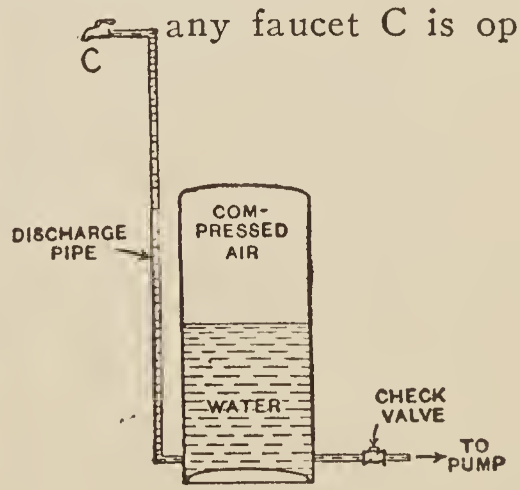


Fig. 15.—Showing How the Air is Compressed in a Pneumatic Tank.
Courtesy of the MacMillan Co.

EXPERIMENT No. 5

To make and operate a pneumatic tank.

Arrange the apparatus as shown in Fig. 16. It is necessary to fasten the stopper in the bottle very securely. Do this as follows: Insert two elbows into the two-hole rubber stopper and twist the stopper firmly into the neck of the bottle. Next loop three strong rubber bands together as shown in Fig. 17, pass a stout cord over the stopper and wind the **stretched** rubber bands around the neck and cord. Now slip the last end of the bands under the last winding to hold it, (1) Fig. 18, then tie the ends of the cord up over the stopper, (2) Fig. 18, and you will find that the stopper is very secure.

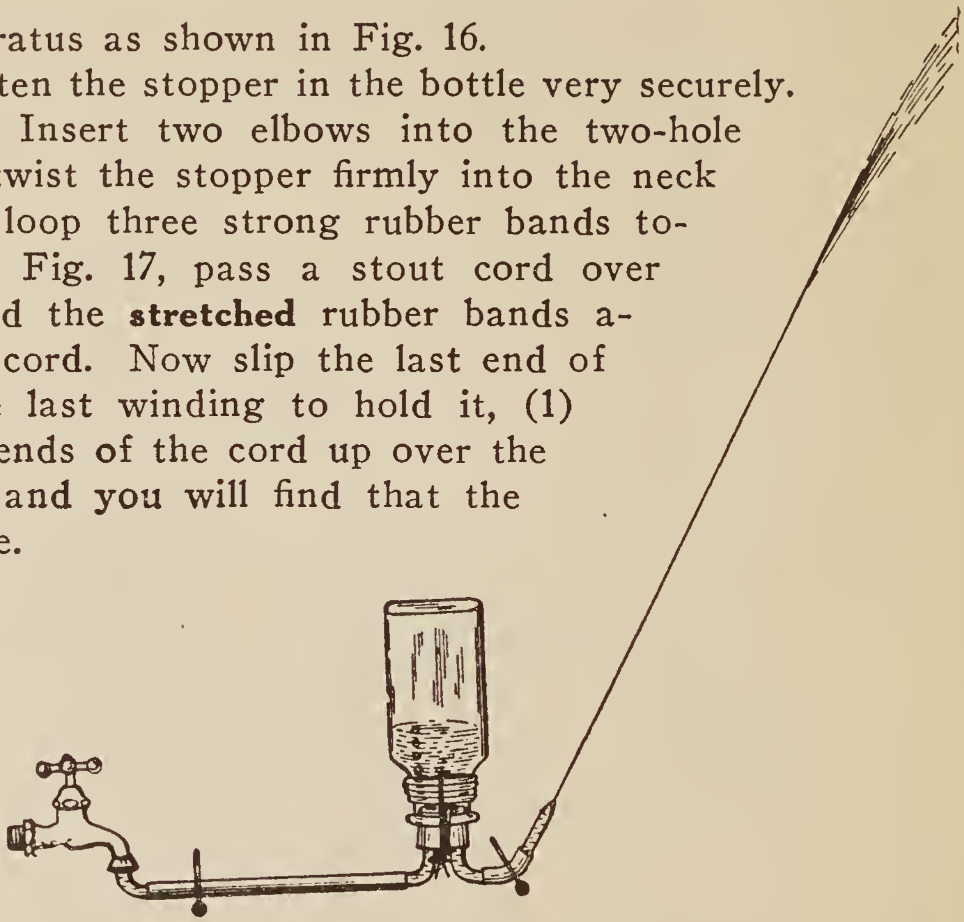
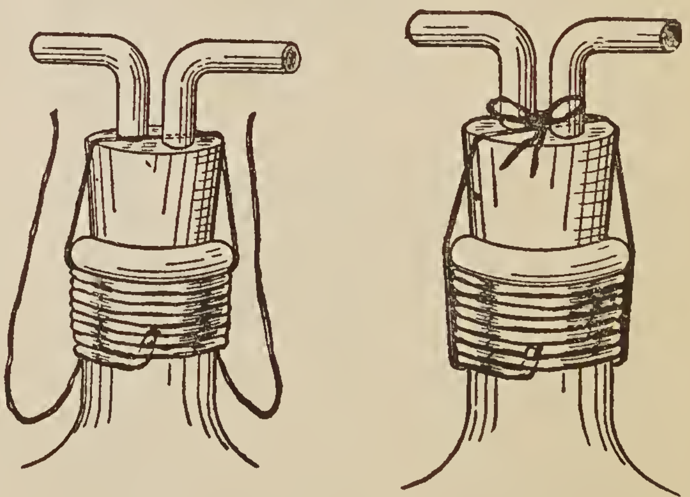


Fig. 16.—Operating a Pneumatic Tank.

Fig. 17.

The **stretched** rubber bands make a very secure tie because each stretched winding grips the cord. You will use this tie often in your experiments.

Note—You can use the tee and one-hole stopper instead of the elbows and two-hole stopper if you prefer.



(1) (2)

Fig. 18.—Showing How to Make a Stopper Secure by Means of Cord and Looped Rubber Bands.

Now: open the clip on the hose, open the faucet Fig. 16, slightly, run water into the bottle until it is half full, close the faucet, close the clip on the hose, remove stopper from faucet, point the nozzle upward, and open the clip on the nozzle.

Does the compressed air force the water out with surprising force?

If you have no water faucet handy, illustrate the pneumatic tank as shown in Fig. 19. Fill the bottle half full of water, tie the stopper in place, force air in with your mouth or with a bicycle pump, and observe the stream as before.

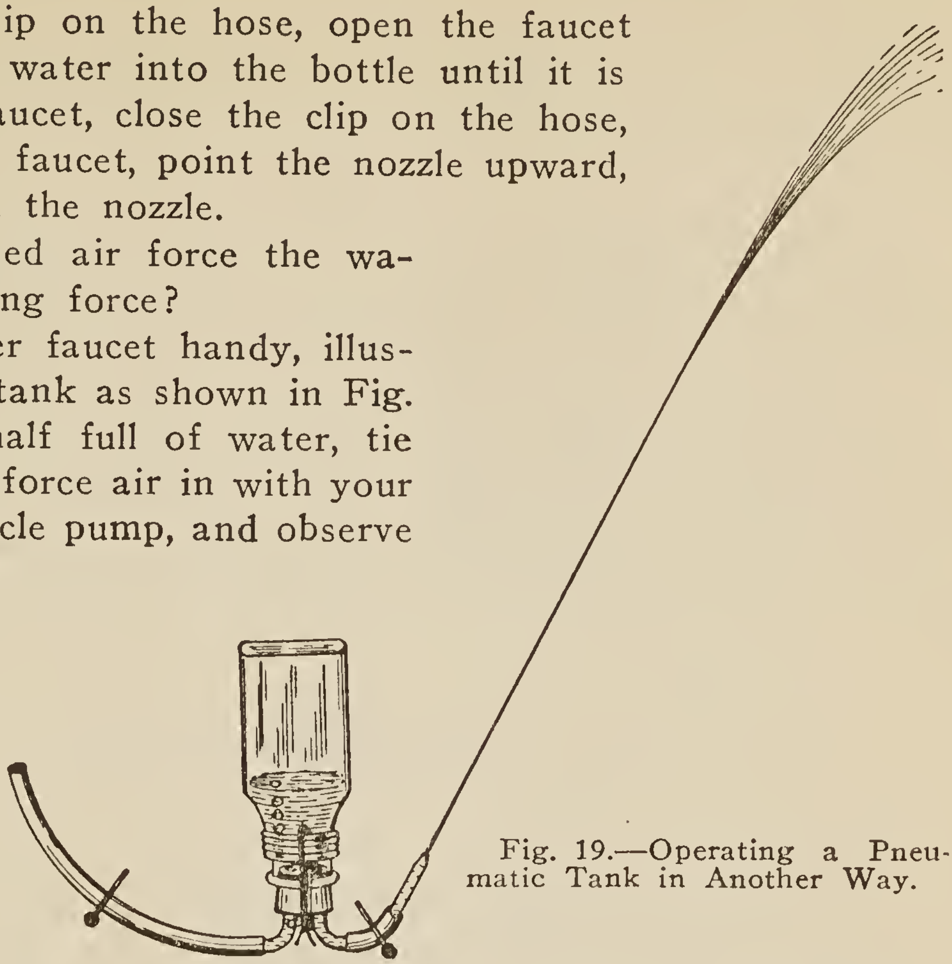


Fig. 19.—Operating a Pneumatic Tank in Another Way.

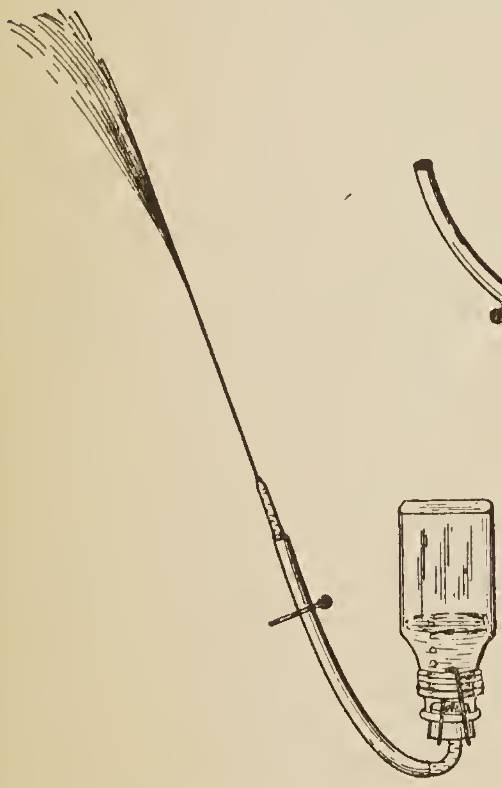


Fig. 20.

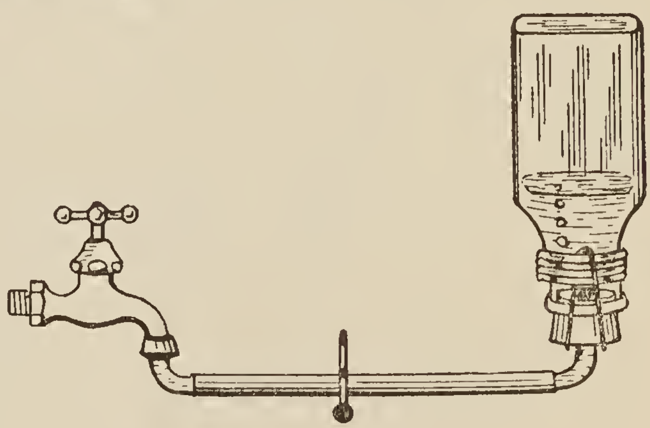


Fig. 21.

Find a larger bottle, which your stoppers will fit, and repeat these experiments.

You have shown here how the compressed air in a pneumatic tank forces the water out through the discharge pipe. Repeat and make experiments of your own.

Note—Do not attempt to fill the bottle more than half full of water because the air pressure increases rapidly as the air is compressed and it blows out the nozzle or separates the rubber tubes from the elbows.

RAPID FIRE WATER GUN

GAME No. 2

Arrange the bottle as shown in Fig. 21 and fill it half full of water. Replace the elbow by a nozzle as in Fig. 20 and your rapid fire water gun is complete. Open the clip for an instant only for each shot.

Arrange a battle with one or more on a side, each soldier armed with a rapid fire water gun. A man is wounded when hit on the arm or leg and must afterwards fight without the arm or leg; a man is killed when hit on the body or head. The side loses which first has all of its men killed. Use forts, trenches, tanks, etc.

EXPERIMENT No. 6

To make and operate a pneumatic tank system of water supply.

Arrange the apparatus as in Fig. 22, fill the bottle half full of water as above, open the clip on the discharge tube, and observe the height to which the compressed air lifts the water.

Repeat with the apparatus as in Fig. 23. Do you observe that the stream from the lower nozzle is longer than that from the upper; that is, that in the pneumatic system also the pressure is always greater at the lower faucet?

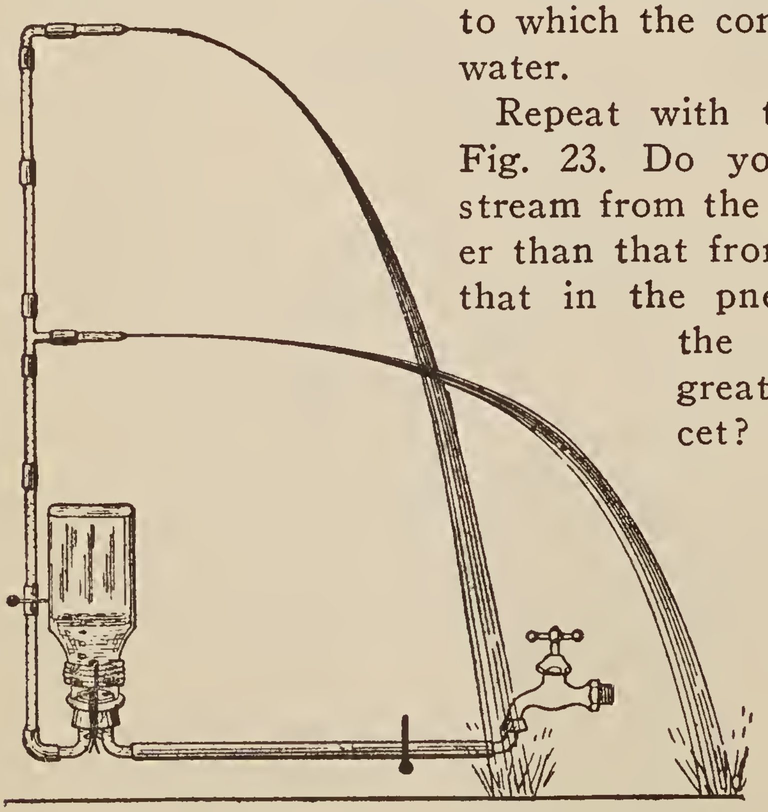


Fig. 23.—Water Pressure is Greater at the Lower Faucet.

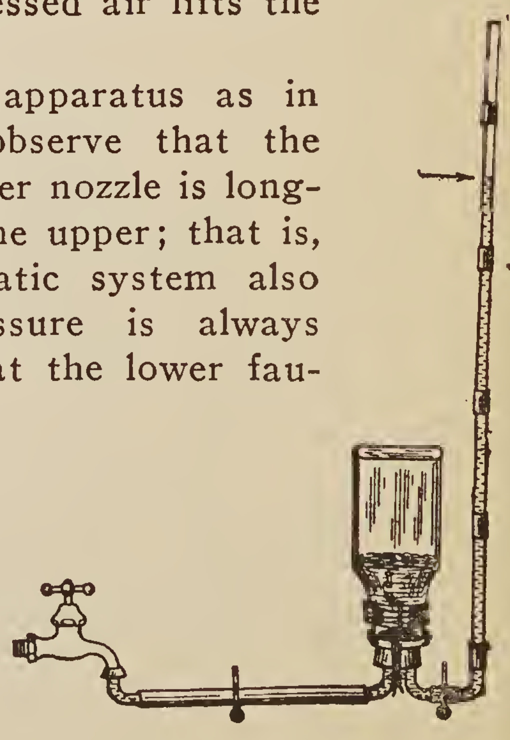


Fig. 22.—The Compressed Air in a Pneumatic Tank Forces Water Up the Discharge Pipe.

Repeat with the apparatus as in Fig. 24. Do you observe that the streams are of the same lengths, that is, that the pressures are equal at faucets on the same level?

You have shown here how the compressed air in a pneumatic tank forces water up to the faucets above; also that the greater pressure is at the lower faucet, and that the pressures are equal at faucets on the same level.

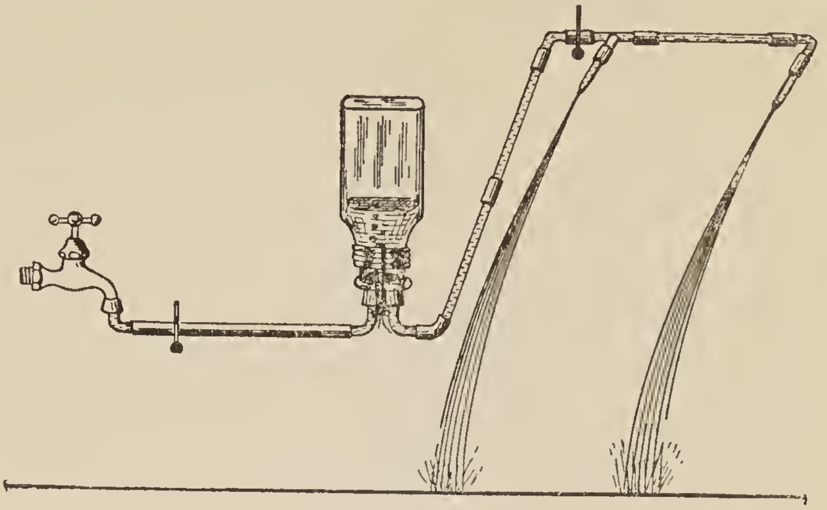


Fig. 24.—The Water Pressures are Equal.

WATER AND AIR

EXPERIMENT No. 7

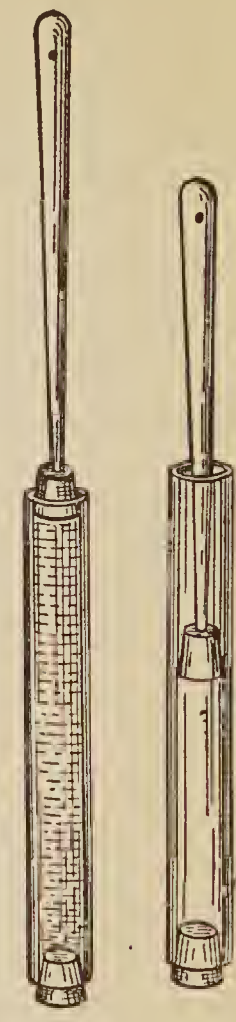
To show that water is incompressible and that air is compressible.

Arrange the apparatus as in Fig. 25, fill the tube with water and try to compress it. You cannot do so because water is nearly incompressible.

Note: Water is slightly compressed by very great pressures; for example, if your tube were 10 in. long and you could apply a pressure of 3000 lbs. per square inch, the water would be compressed 1/10 inch.

Now empty out the water and try to compress the air in the tube as in (2) Fig. 25. You will find that you can do so quite easily because air is quite compressible.

You have demonstrated here that water is incompressible (nearly) and that air is compressible. You know from this that in the pneumatic tank it is the air which is compressed and not the water.



1 2

Fig. 25.—Showing that water is incompressible and that air is compressible.

EXPERIMENT No. 8

To show that compressed air exerts pressure.

Use the apparatus shown in Fig. 26. Wet the inside of the tube, wet the plunger and rub it on a cake of soap to make it slippery, shove the plunger into the tube (1) and let it go suddenly.

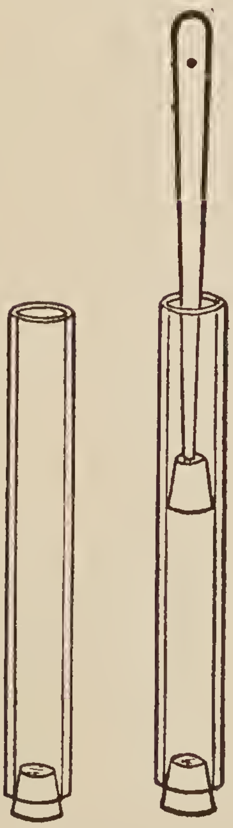
Do you find that the compressed air drives the plunger out violently (2)?

Repeat with a little water above the plunger to serve as a lubricant.

Note: When you shove the handle into the stopper you expand the stopper slightly. You should expand it until it fits the tube snugly but not too tightly.

Hold the apparatus as in (3), Fig. 26 and force the handle in until the compressed air drives out the end stopper.

You have shown here that compressed air exerts pressure and you will understand from this how the compressed air drives the water out of a pneumatic tank;



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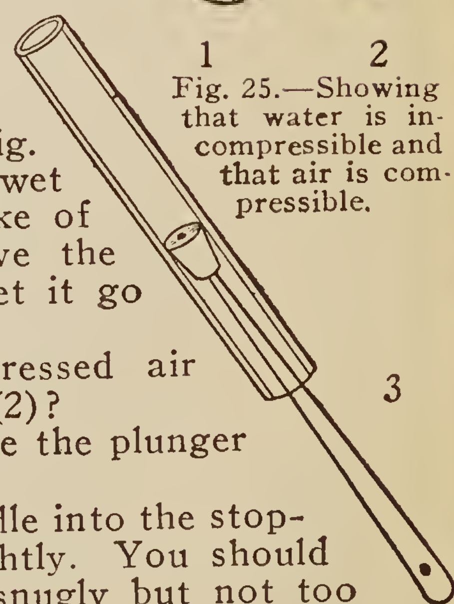

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Fig. 26.—Compressed air exerts pressure.

also you will understand why the tank must be made of steel, namely, to stand the pressure of the compressed air.

TRENCH GUN

GAME No. 3

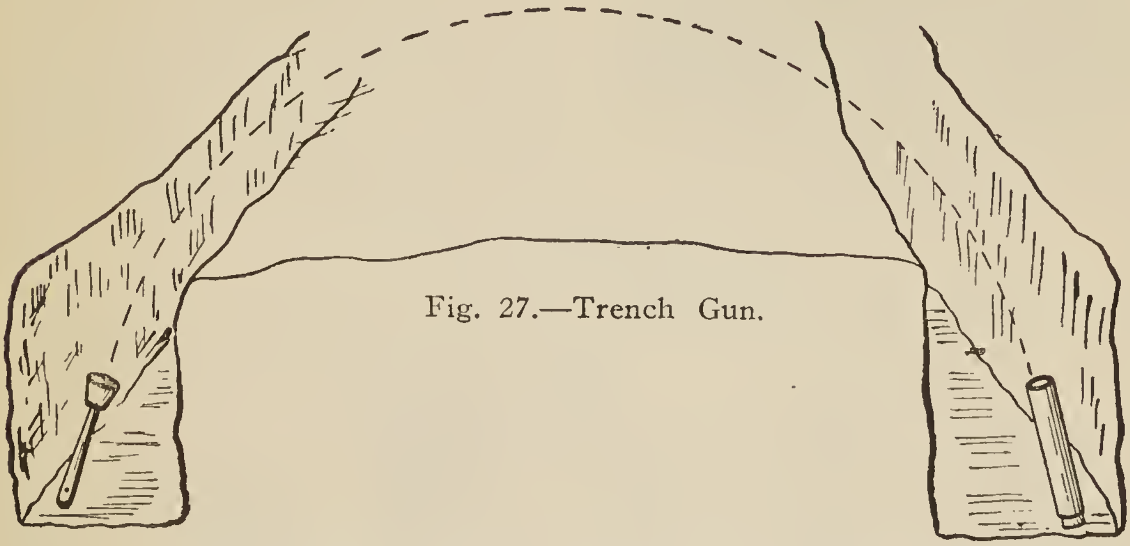


Fig. 27.—Trench Gun.

You can imitate the Stokes trench gun as follows. Put two long strips of paper on the ground three feet apart to represent the enemy trench. Now go back 20 or 30 feet or more, point the tube upward and toward the enemy trench, force the plunger in and release it suddenly. The game is to try to drop the bomb, that is, the plunger, into the enemy trench. The winner is the one who does it most often in a given number of trials.

Note: Keep the inside of the tube wet, the plunger wet and slippery with soap, and a little water above the plunger.

HEIGHT AND DISTANCE CONTEST

GAME No. 4

Use the apparatus as above. The game is to see who can shoot the plunger to the greatest height and to the greatest distance.

POP GUN

GAME NO. 5

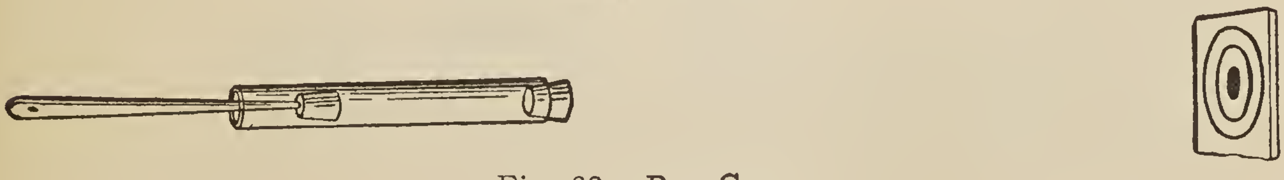


Fig. 28.—Pop Gun.

Use the apparatus as a pop gun, Fig. 28. The games are: first, to try to hit a bull's eye, with the end stopper; second, to see which can shoot it to the greatest distance and the greatest height.

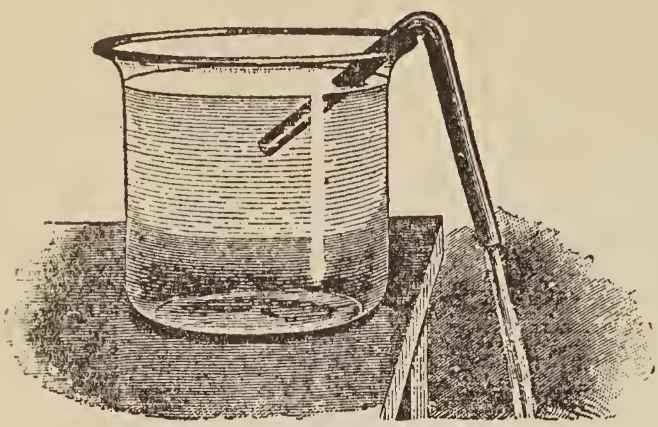


Fig. 29.—A Siphon.
Courtesy of The MacMillan Co.

THE SIPHON

The siphon is used in many water supply systems to make water flow over the top of a storage tank or over a hill from a spring on one side to a house on the other, and so on.

You will first show how the siphon works, then you will show how it is used in water supply system, and later you will show why it works as it does.

EXPERIMENT No. 9

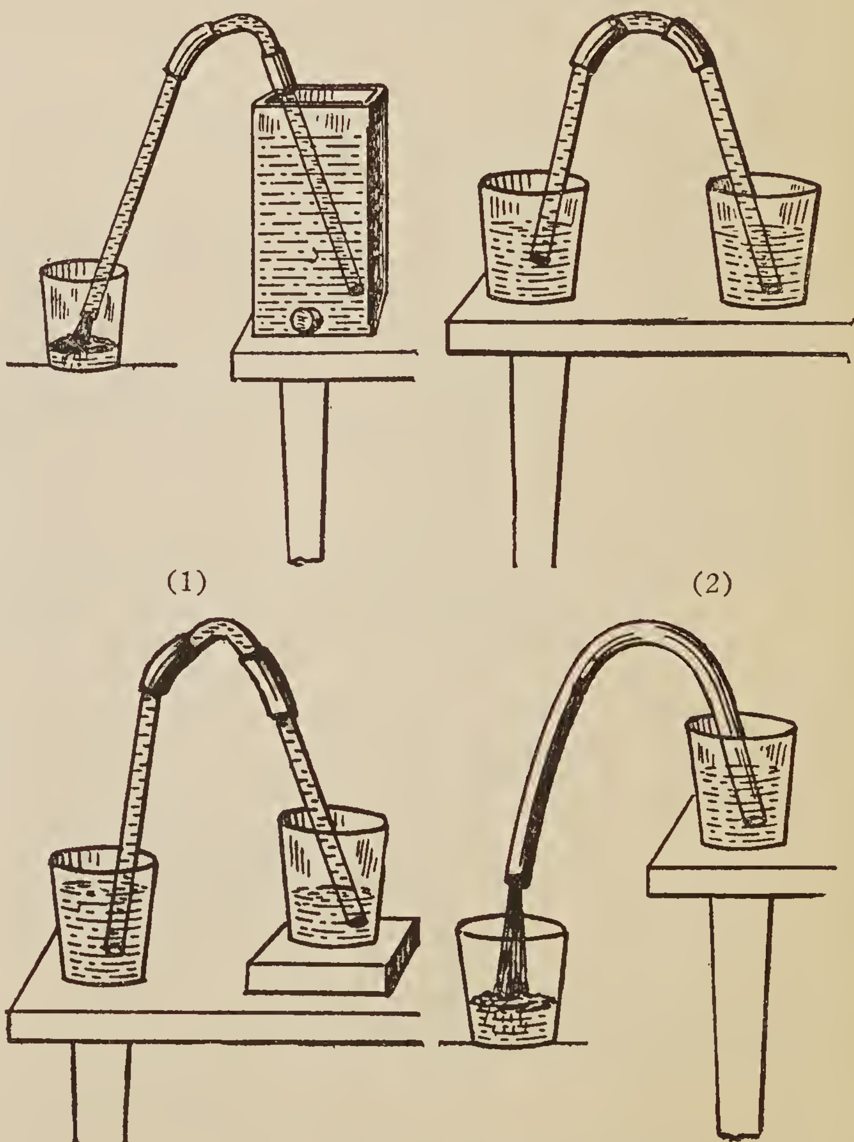
To make and operate a siphon.

Arrange the apparatus as in (1), Fig. 30. Place one arm of the siphon in the water and while holding the other arm outside the tank below the water level suck the air out of the siphon until the water runs.

Does the water run up hill to the top of the siphon and then down hill into the tumbler?

Siphon water out of a full tumbler into an empty tumbler and while the water is running stand them side by side on the table, (2), Fig. 30.

Does the water stop when the level is the same in both tumblers?



(1) (2) (3) (4)

Fig. 30.—Illustrating the Siphon.

Place one tumbler on a block of wood or a book as in (3), Fig. 30.

Does the water flow from the upper tumbler to the lower, and does the flow again stop when the levels are the same?

Place the block under the other tumbler.

Are the results the same?

Repeat the above experiments with the rubber hose, (4), Fig. 30, used as a siphon.

You have shown here: that the water runs uphill in one arm of a siphon and downhill in the other; that it always runs from the higher water level to the lower; and that it stops running when the water levels are the same.

You will show "why" the water runs, in later experiments.

HOW THE SIPHON IS USED IN WATER SUPPLY SYSTEMS

EXPERIMENT No. 10

To show how the siphon is used in water supply systems.

It is rather difficult to make a water-tight connection in the bottom of a water tank and in many cases it is not done, but instead the water is siphoned out over the top, as shown in Fig. 31.

Illustrate this as shown in Fig. 32.

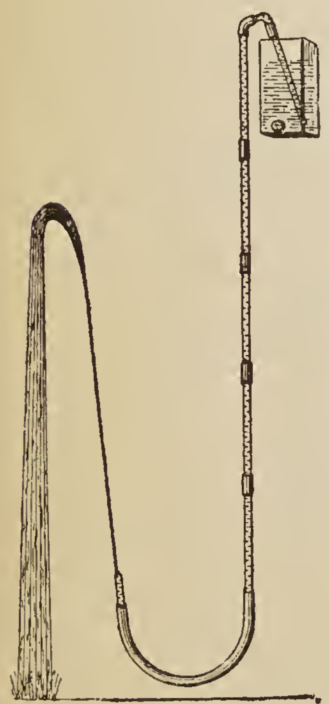


Fig. 32.—Showing How Water is Siphoned Out of an Elevated Tank.

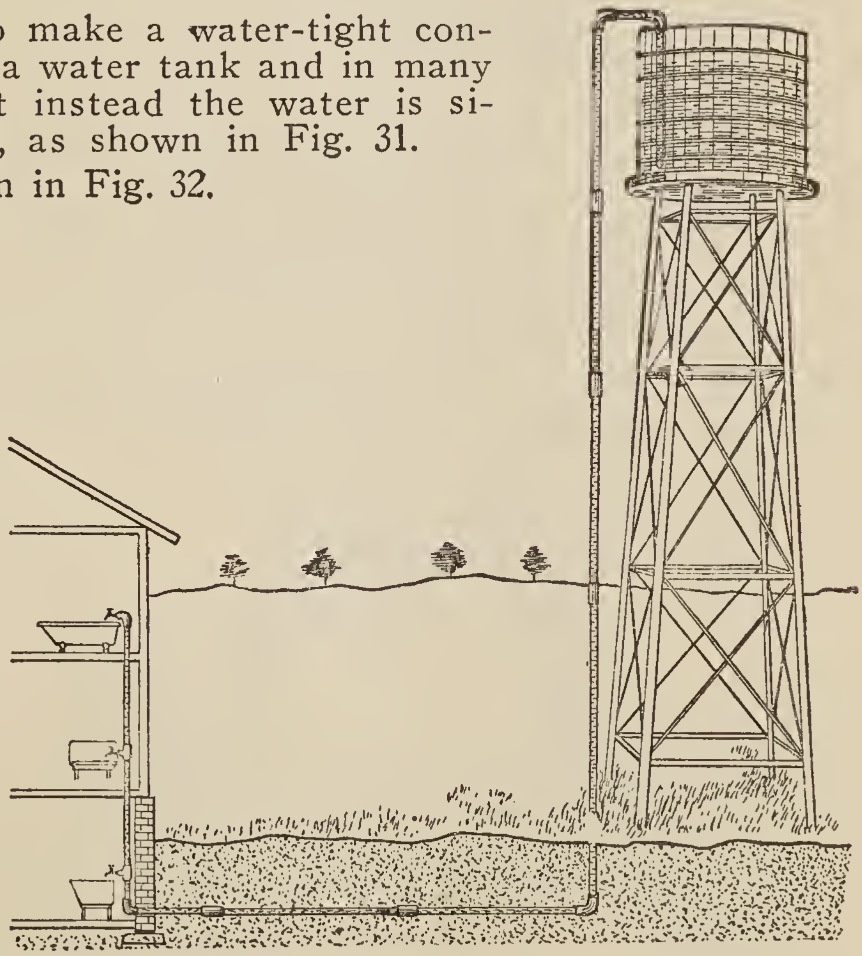


Fig. 31.—The Arrangement of Piping Used to Siphon Water Over the Top of a Storage Tank.

In some cases it happens that there is a good spring of water on one side of a hill and the home in which the water is wanted is on the other side. If the highest point

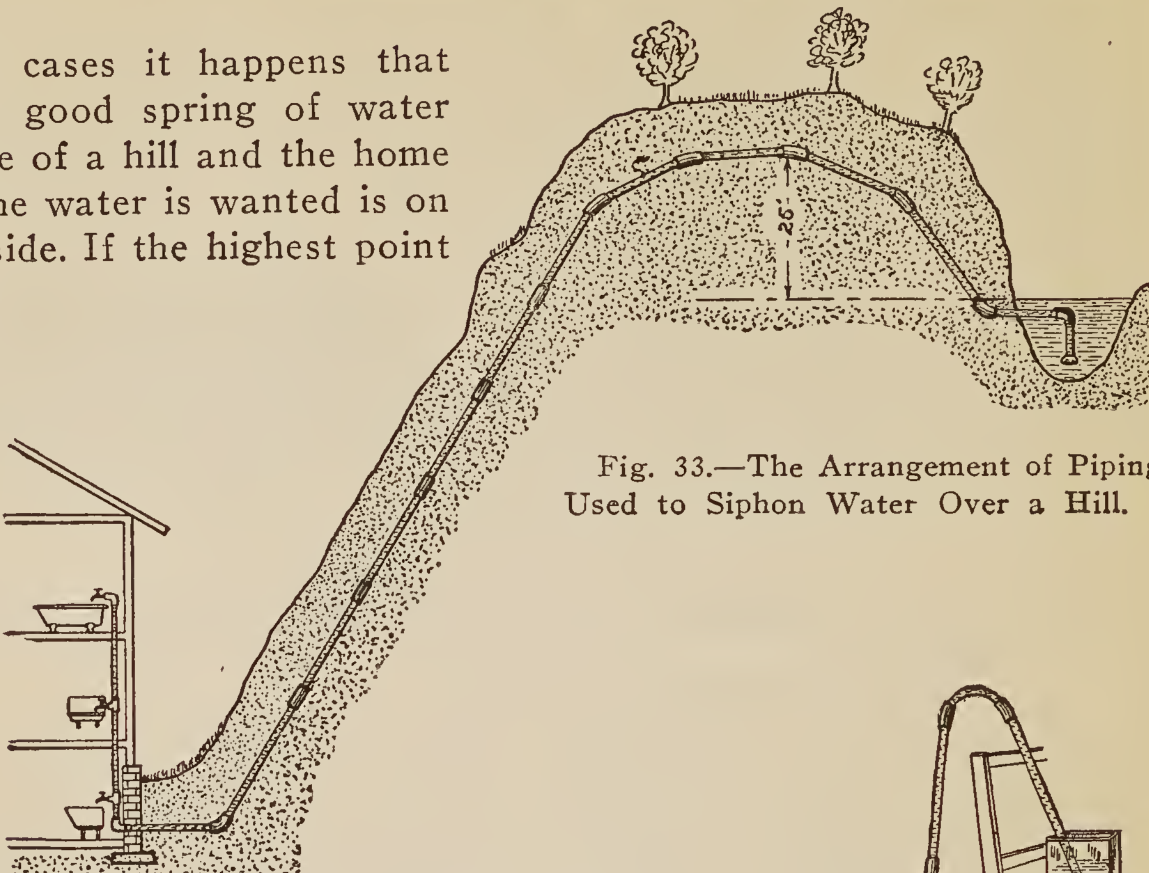


Fig. 33.—The Arrangement of Piping Used to Siphon Water Over a Hill.

of the siphon is not more than about 25 feet (34 feet is the theoretical limit) above the water surface in the spring, and if the house faucets are below the level of the water in the spring, the water can be siphoned over the hill as shown in Fig. 33.

Illustrate this as shown in Fig. 34, where the back of the chair represents the hill.

Fig. 34.—Showing How Water is Siphoned Over a Hill.

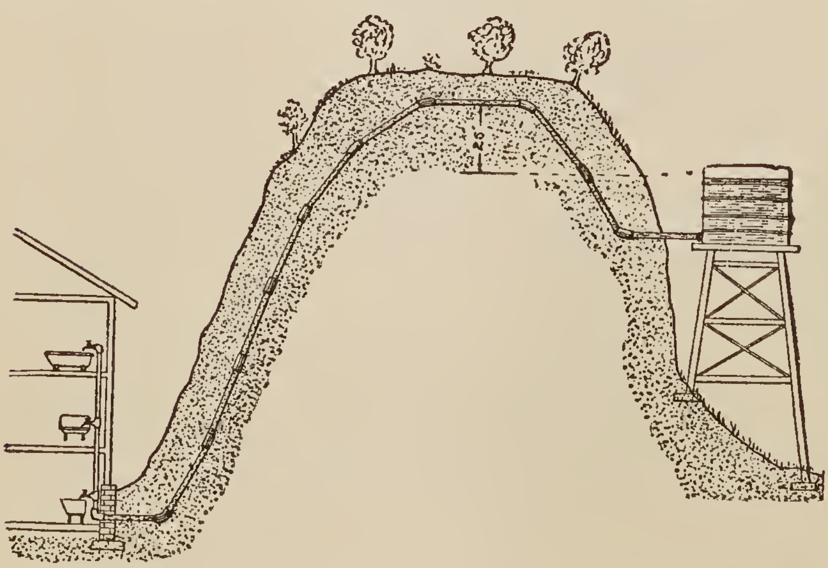


Fig. 35.—The Arrangement of Piping Used to Siphon Water Over a Hill from a Storage Tank.

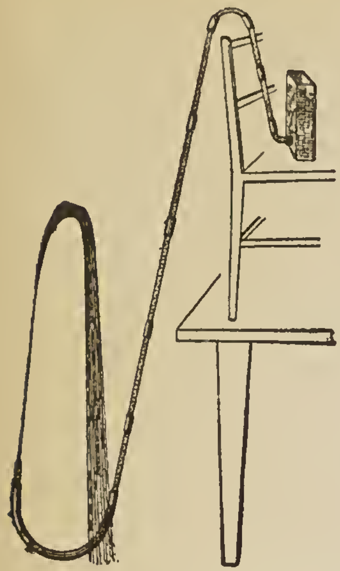


Fig. 36.—Siphoning Water Over a Hill from a Tank.

Water can be siphoned from a storage tank or reservoir over a hill as well as from a spring and the siphon can start at the bottom of the reservoir if this is more convenient, see Fig. 35.

Illustrate this as shown in Fig. 36.

You have here illustrated three ways in which the siphon is used in water supply systems. You will show later why a siphon cannot lift water over a rise of more than about 25 feet and why the greatest theoretical lift is 34 feet.

HOW TO START A LARGE SIPHON

EXPERIMENT No. 11

To illustrate different ways of starting a large siphon.

You could not start a large siphon by sucking the air out of it with your mouth. How then are you going to start it? You will illustrate three ways.

The object in all cases is to get the air out of the siphon and this is usually done by filling it with water.

In the case illustrated in Fig. 37, the faucets are all closed and the air is driven out of the siphon by pumping water into the tank through the siphon. The check valve prevents the water from running back into the pump, and when the faucets are opened the water runs.

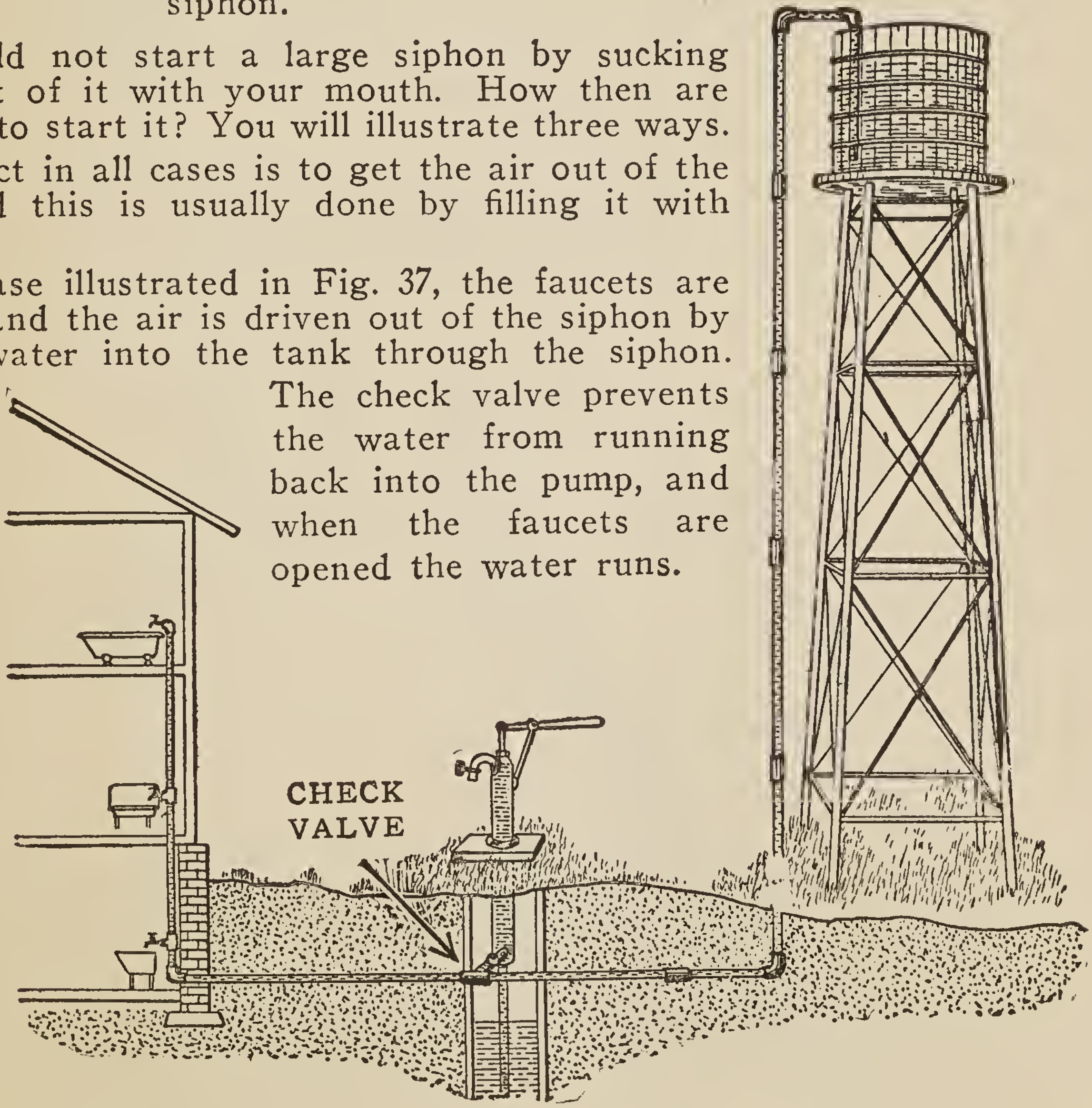


Fig. 37.—The Large Siphon is Started by Pumping Water into the Tank through the Siphon.

This experiment is illustrated by means of the apparatus shown in Fig. 38. The faucet here represents the pump. Start with the tube empty except for the air in it, close the clip under the nozzle, open the faucet until the tank is full of water, close the faucet, and open the clip.

Does the water run through the siphon to the nozzle?

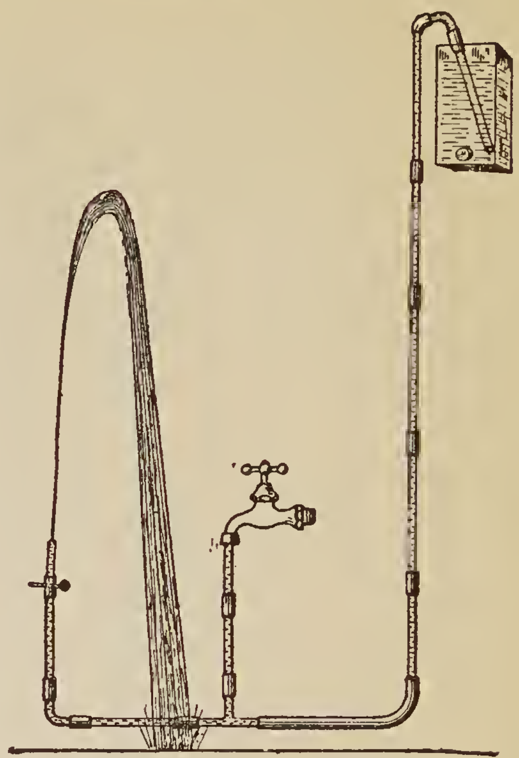


Fig. 38.—Illustrating One Method of Starting a Large Siphon.

When the water is siphoned over a hill from a spring, the siphon is usually started by connecting it to the suction side of a pump placed on the other side of the hill in or near the house, as shown in Fig. 39.

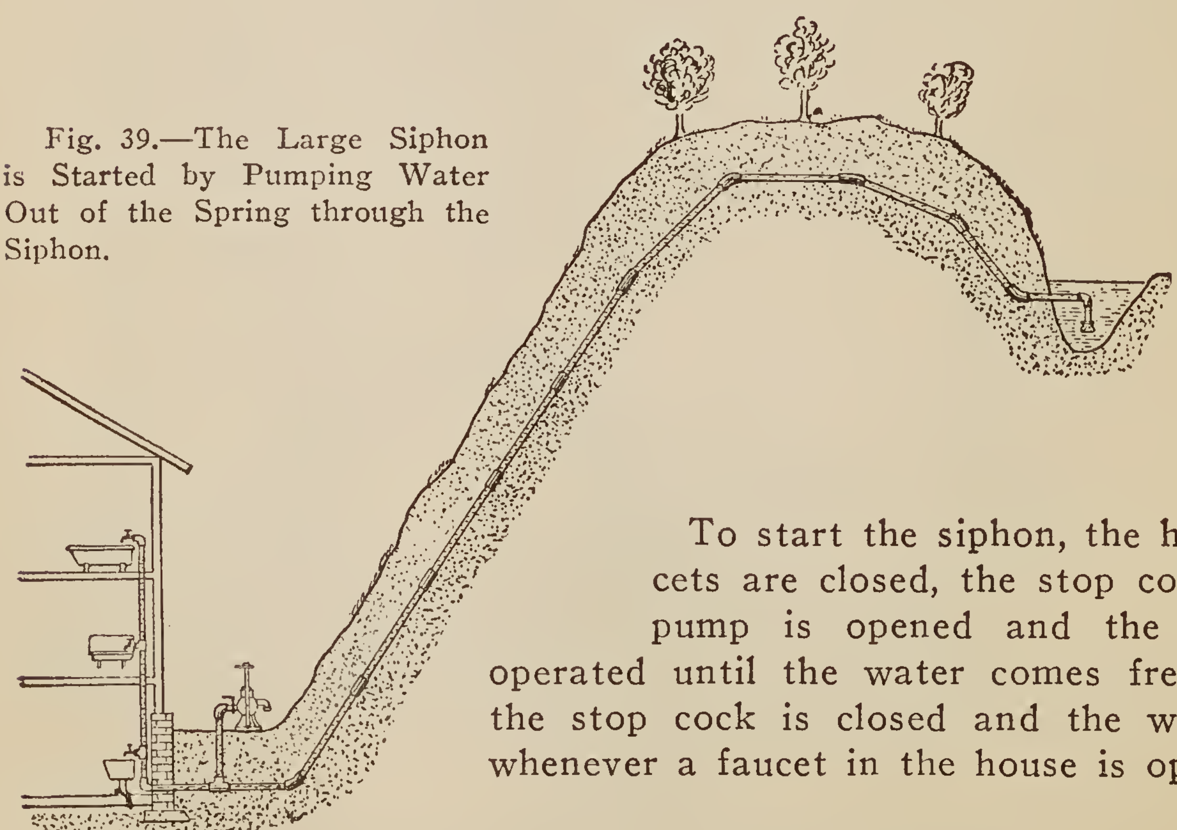


Fig. 39.—The Large Siphon is Started by Pumping Water Out of the Spring through the Siphon.

To start the siphon, the house faucets are closed, the stop cock at the pump is opened and the pump is operated until the water comes freely; then the stop cock is closed and the water runs whenever a faucet in the house is opened.

This is illustrated by arranging the apparatus as shown in Fig. 40; the tee branch represents the pump connection and the end branch represents the house pipe.

Close the house pipe, apply your lips to the tee branch (to represent the working of the pump) and suck air out of the siphon until the water flows, then close the tee branch and open the house pipe. Does the water flow?

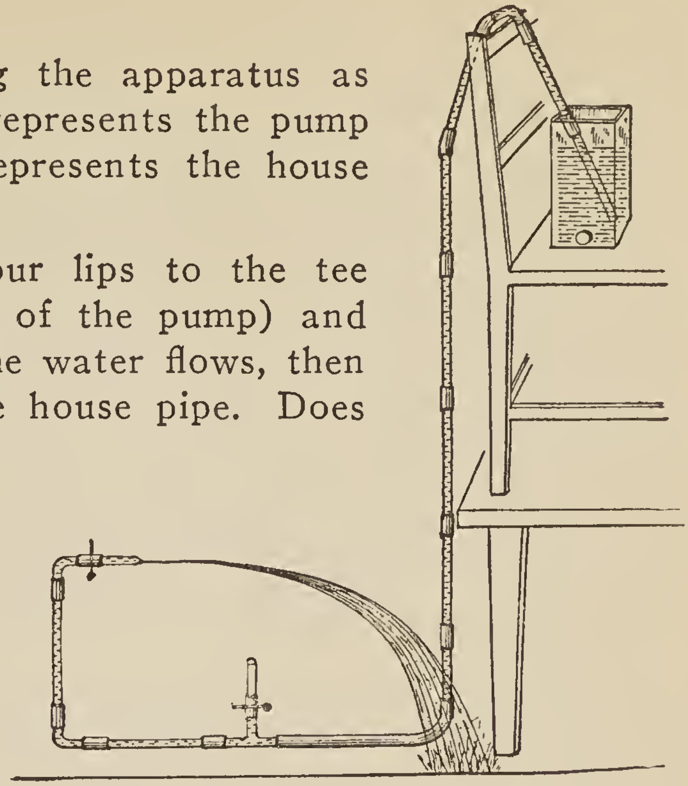


Fig. 40.—Starting a Large Siphon.

In many cases the water is siphoned over the top of a hillside well to a house at a lower level and the siphon is started by means of a pump near the house as illustrated in the last experiment. Generally, however, a small storage tank of water at the top of the siphon is used to start it, see Fig. 41. The small storage tank is filled by means of a pump (not shown), or by means of a pail used to dip water from the well.

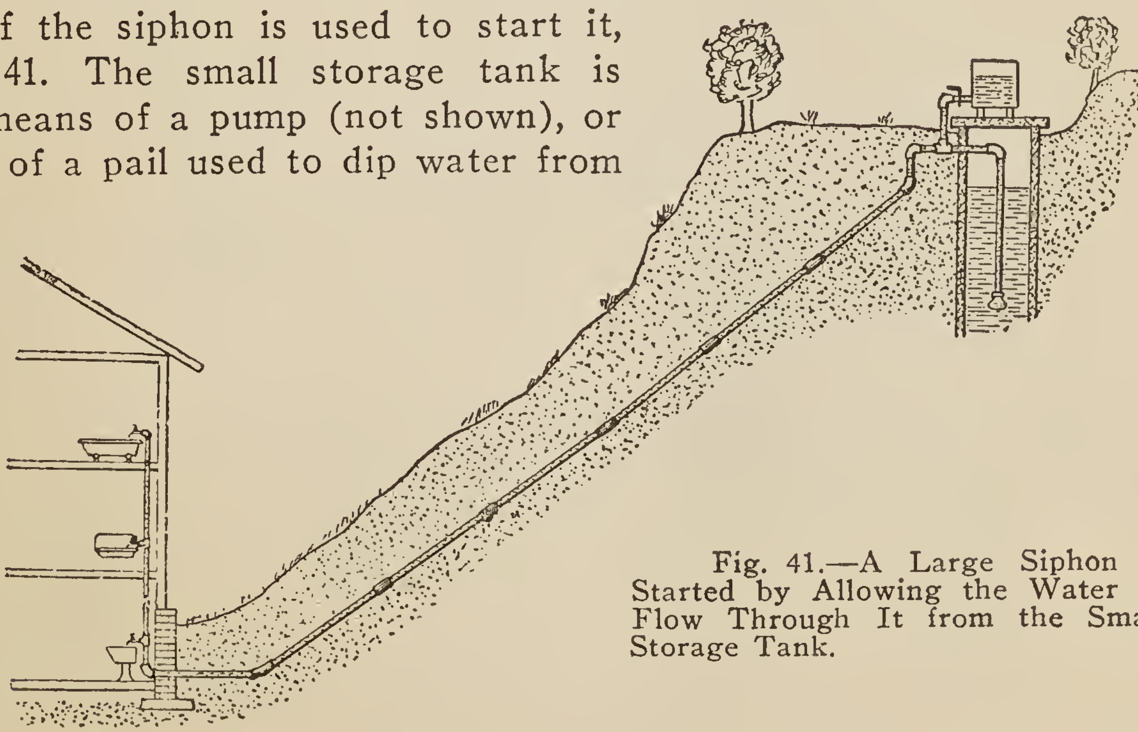


Fig. 41.—A Large Siphon is Started by Allowing the Water to Flow Through It from the Small Storage Tank.

Illustrate this method of starting a large siphon with the apparatus shown in Fig. 42. The tee at the top is connected with the metal tank, which here represents the small storage tank, the large pail represents the hillside well, and the long arm of the siphon represents the pipe to the house.

Open the house faucet, then open the tee connection to the storage tank. Does the water flow down the long arm of the siphon? Now close the house faucet and observe that the water runs down the short branch into the pail. Now close the tee connection and open the house faucet. Does the siphon run?

Note: The storage tank needs to be filled only when the siphon stops, which may be only once or twice a year.

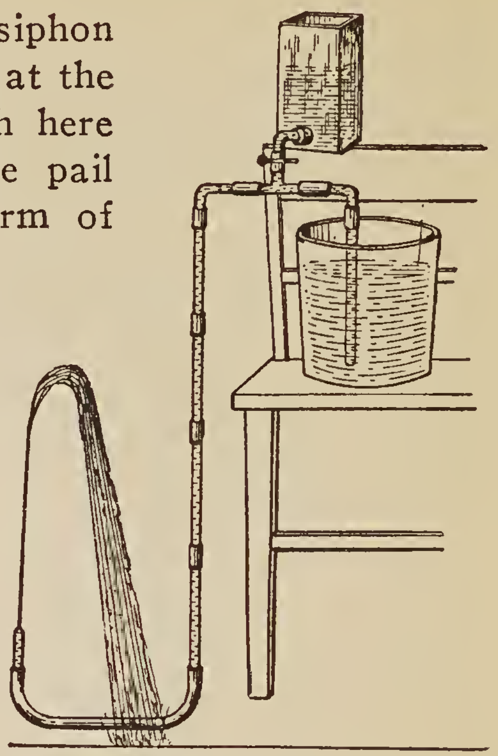


Fig. 42.—Showing How a Large Siphon is Started by Means of Water from a Small Storage Tank.

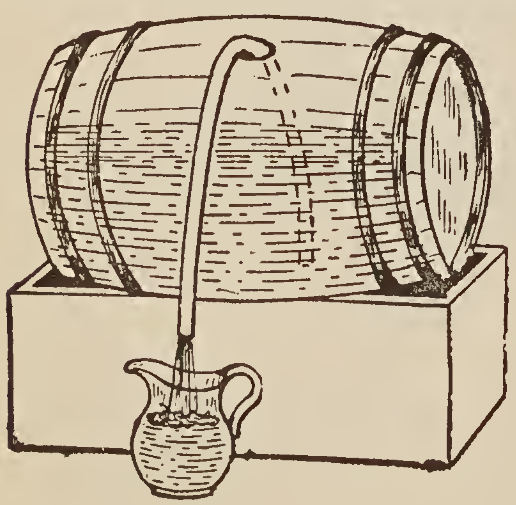
OTHER USES OF THE SIPHON

EXPERIMENT No. 12

To illustrate other uses of the siphon.

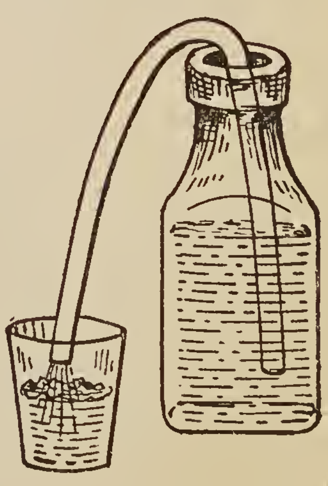
You can siphon cider, or other liquids, out of a barrel by means of a rubber tube, (1) Fig. 43.

Illustrate this as in (2) Fig. 43, where the bottle represents the barrel and the neck of the bottle the bung hole.



1

Fig. 43.—Siphoning Cider Out of a Barrel.



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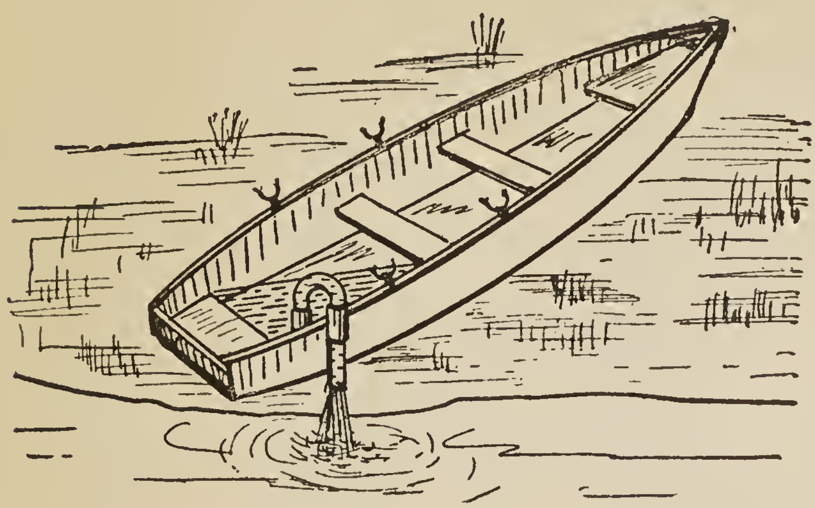

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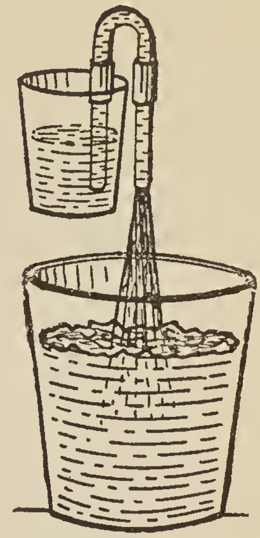
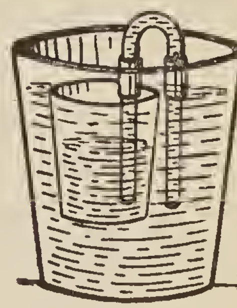


2

Fig. 44.—Siphoning Water Out of a Boat.

You can siphon water out of your boat when it is out of the water, (1) Fig. 44, but not when it is afloat.



3

Use a tumbler to represent your boat and show that you can siphon water out of it when it is out of the water, (2) Fig. 44; but that you siphon water **into** the boat if it is afloat, (3) Fig. 44, because the water outside the boat is higher than that inside.

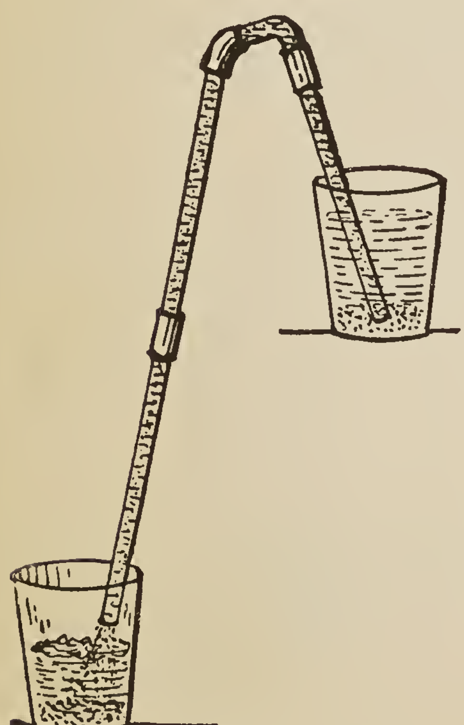


Fig. 45.—Siphoning Sand.

You can siphon sand, gravel, and mud **with** the water when necessary. Illustrate this by siphoning sand or mud with the water from one tumbler to another, Fig. 45.

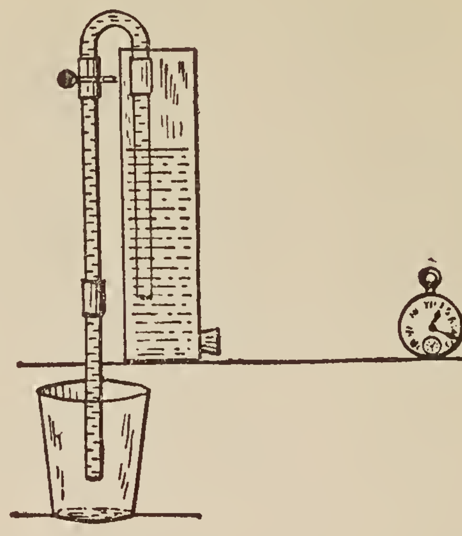
VELOCITY OF FLOW

EXPERIMENT No. 13

To show that the velocity of the water in a siphon is greater, the greater the distance, between the water levels about the two arms.

Arrange the siphon with a small difference in water level as shown in (1) Fig. 46 and allow the water to run for 15 seconds; then arrange it with a greater difference as in (2) Fig. 46 and again allow the water to run for 15 seconds.

Does more water flow in (2) than in (1), that is, is the velocity greater the greater the difference in water level?



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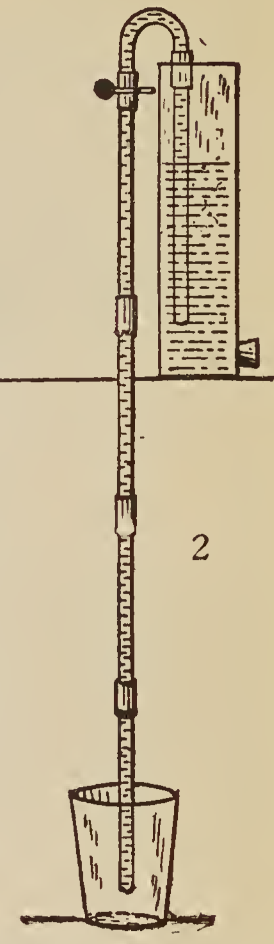


2

Fig. 46.—Velocity of Water in a Siphon.

OTHER SIPHONS

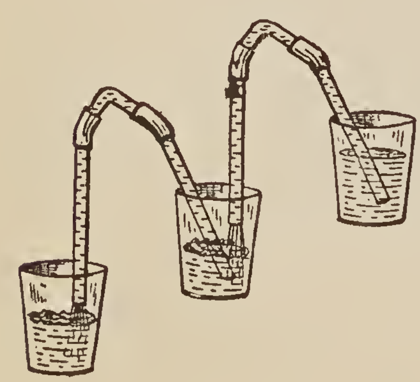
EXPERIMENT No. 14

To make and operate a double siphon and a three legged siphon.

Start a double siphon, (1) Fig. 47. Raise the tumblers one at a time, then two at a time.

Does the water always flow from the upper tumbler or tumblers to the lower and does it always stop flowing when the water levels are the same?

Start a three legged siphon, (2) Fig. 47 and repeat the above experiments. Are the results the same?



1

2

Fig. 47.—Double Siphon and Three-legged Siphon.

HOW TO START A SMALL SIPHON

EXPERIMENT No. 15

To illustrate two ways of starting a small siphon.

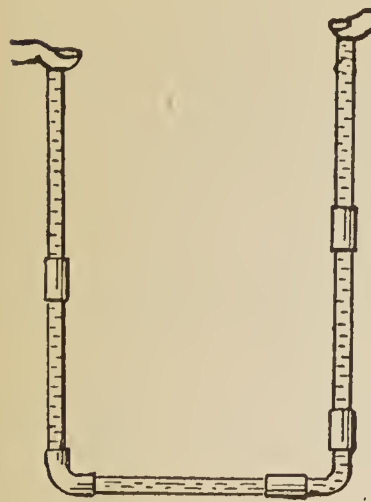
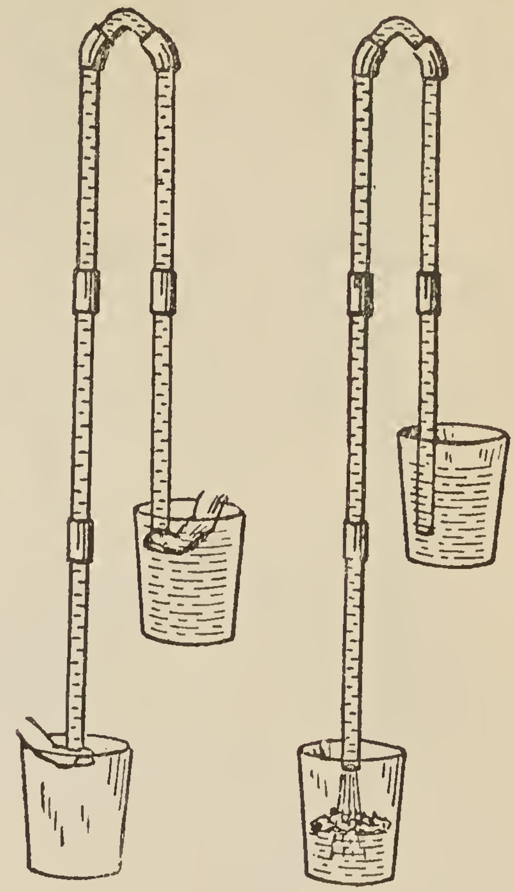


Fig. 48.—Starting a Small Fountain.

1

You have been starting your small siphon by sucking air out of the long arm. You can also start it as shown in (1) Fig. 48. Fill the siphon with water to force the air out, close the ends with your fingers, invert the siphon, and when the upper end is under water in the upper tumbler remove both fingers, (2) Fig. 48.

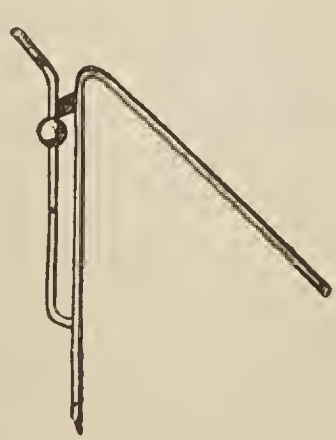


2

Glass siphons used to siphon acid have a starting tube on the outside arm, (3) Fig. 48.

Illustrate the use of this by siphoning water out of a bottle with the siphon shown in (4) Fig. 48. Place the upper end in the water, close the lower end, suck out a little air, and open the lower end.

Practice until you can start the siphon without getting water (representing the acid) on your fingers or lips.



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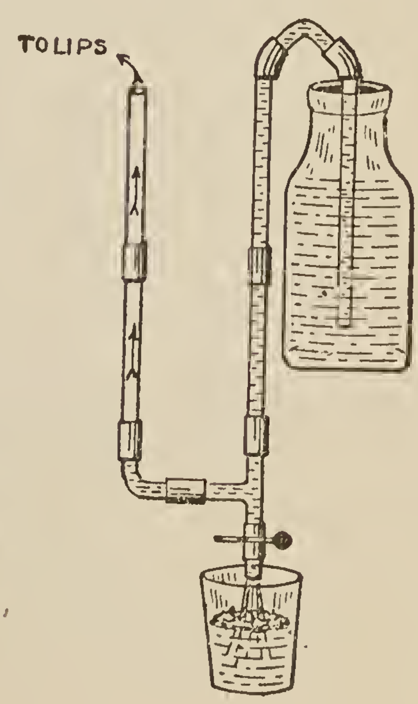

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AN ENCLOSED FOUNTAIN

EXPERIMENT No. 16

To make and operate an enclosed fountain.

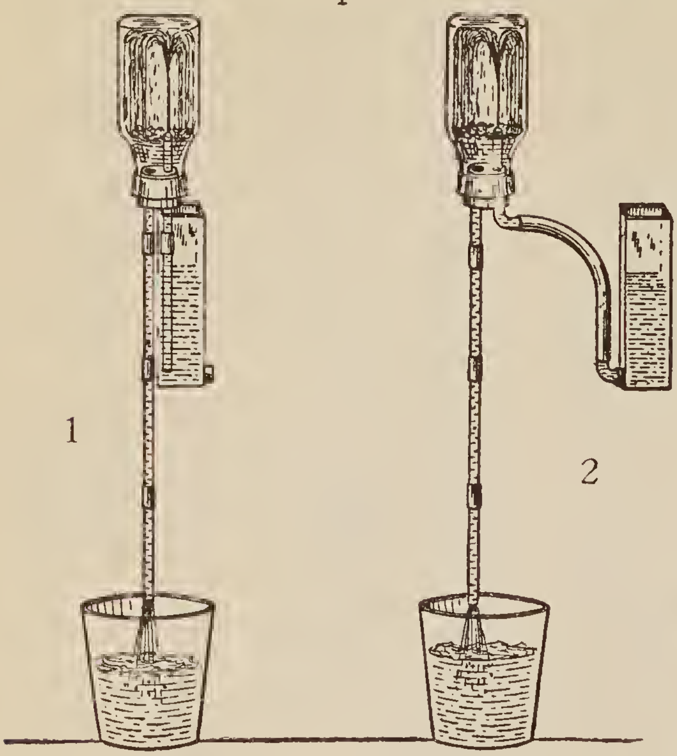


Fig. 49.—An Enclosed Fountain.

Arrange the apparatus as shown in (1) Fig. 49; this is really a siphon with a bottle at the top. Start with 2 inches of water in the bottle, insert the stopper with tubes, invert the whole apparatus, and put the short arm in the tank filled with water.

Does the water run and is there a fountain in the bottle?

Arrange the apparatus as in (2) Fig. 49, lift the tank until there is about 2 inches of water in the bottle, then arrange as shown.

Is there a fountain in the bottle? Repeat both of these experiments but use instead of the bottle, a wide glass tube closed at the top with a solid rubber stopper, (1) Fig. 50.

Make two fountains as shown in (2) Fig. 50, one enclosed and one in the open.

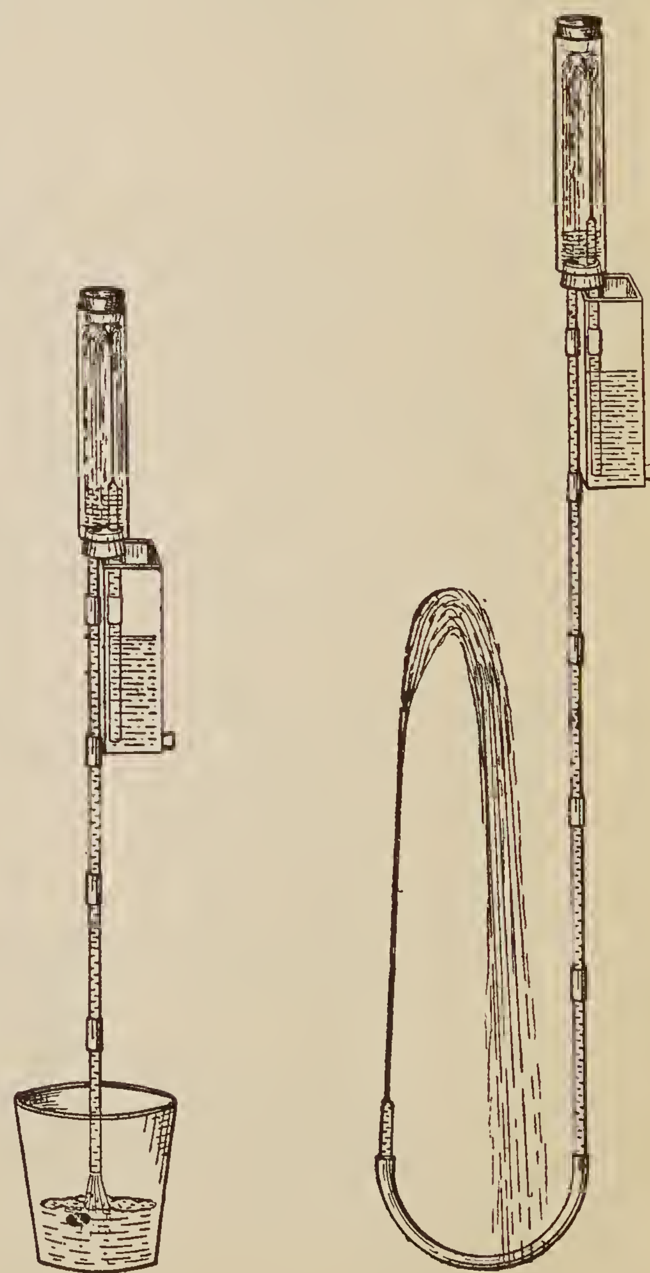


Fig. 50

ATMOSPHERIC PRESSURE

You have made a number of experiments with siphons and you have learned how they act under different circumstances; you will now make some experiments which will help you to understand "why" they act as they do.

Water moves through a siphon because it is forced to do so by atmospheric pressure. You will first make a number of experiments to show that the atmosphere exerts pressure and then you will show how and why this atmospheric pressure forces water through a siphon.

AIR HAS WEIGHT

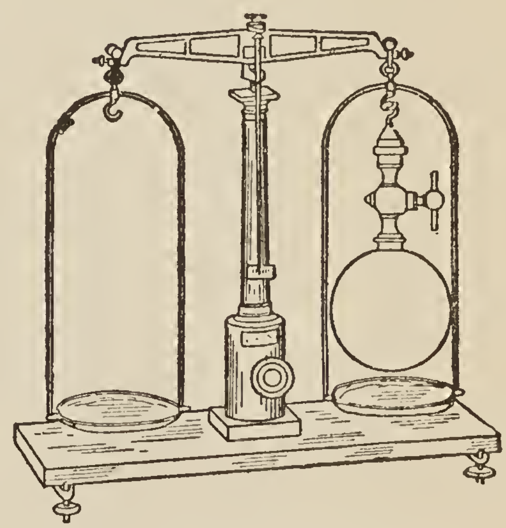


Fig. 51.—Weighing Air.
Courtesy of the MacMillan Co.

If you were asked the question "How much does air weigh?", you would probably answer off hand, "Air has no weight at all." Air, however, has considerable weight and it would take a very strong man indeed to carry a weight equal to that of the air in a house of medium size.

You cannot weigh air with the apparatus you have at hand but this is how it is done. The apparatus used is illustrated in part in Fig. 51. The air is pumped out of the flask, by means of an air pump (not shown). The flask is then balanced exactly on the fine scales and air is admitted to the flask again. It is found that the flask weighs more when it is filled with air than when it is empty, and this proves that air has weight.

A cubic foot of air, at the surface of the earth and at ordinary temperatures is found in this way to weigh about 1¼ oz. This is not a great weight, but when you come to calculate the weight of air in a house of medium size you find that it amounts to a very great deal, for example, make the following calculation:

> A house with a flat roof is 40 feet long, by 30 feet wide, by 24 feet high; find the weight of air in it, neglecting the space occupied by partitions, furniture, etc.

The house contains 40 x 30 x 24 = 28,800 cubic feet of air, and since each cubic foot of air weighs $1\frac{1}{4}$ ozs.—

the house contains 28,800 x $1\frac{1}{4}$ = 36,000 oz. of air, and since there are 16 ozs. in 1 ℔.—

the house contains $\frac{36000}{16}$ = 2250 ℔s. of air.

The house contains 2250 ℔s. of air or over a ton of air (1 ton = 2000℔s). This is a very astonishing fact, especially to those of us who have never thought of air as having any weight at all.

AIR EXERTS PRESSURE

You have learned from your lessons in Physical Geography at school that we live at the bottom of an ocean of air — the atmosphere — which is many miles deep; and when you remember that a cubic foot of air weighs $1\frac{1}{4}$ ozs. you are in a position to see that the atmosphere must exert great pressure on everything at the earth's surface.

It has been found by repeated experiments that the atmosphere exerts a pressure of 14.7 ℔s. (nearly 15 ℔s.) on each square inch of everything at the earth's surface. This means, for example, that on every square inch of our bodies the atmosphere exerts a pressure of 14.7 ℔s. We might think that this would crush our bodies, until we remember that everything inside our bodies exerts the same pressure outward, our blood, the air in our lungs, etc.

A pressure of 14.7 ℔s per square inch is equal to the pressure at a depth of 34 feet under water, that is, if the air could be removed from the earth and be replaced by water, it would require a depth of 34 feet of water all over the earth to produce a pressure equal to that produced by the atmosphere, namely, 14.7 ℔s. per square inch.

You will now make experiments to show that the atmosphere exerts pressure.

EXPERIMENT No. 17

To show that the atmosphere exerts pressure.

Make a U tube, Fig. 52, run water through the tube until all the air bubbles are gone, then empty out part of the water until the U

is a little more than half full. The water in the two arms is then at the same level.

Now apply your lips to the coupling on one arm, suck out the air, and close the clip. Do you observe that, when you suck out the air, the water in the open arm descends while that in the other arm rises?

The explanation is as follows. Everything on the earth is at the bottom of an ocean of air many miles deep, and since this air has weight it exerts pressure on everything on the earth. Now when both arms of the U tube are open, the water level is the same in both and the pressure of the air on the water surface in each is the same, namely, the pressure of the atmosphere. When you remove the air from the closed side, however, you remove the pressure of the atmosphere from this side and the pressure of the atmosphere in the open side forces the water down on the open side and up the closed side. This experiment shows you that the atmosphere exerts pressure.

Repeat and make experiments of your own.

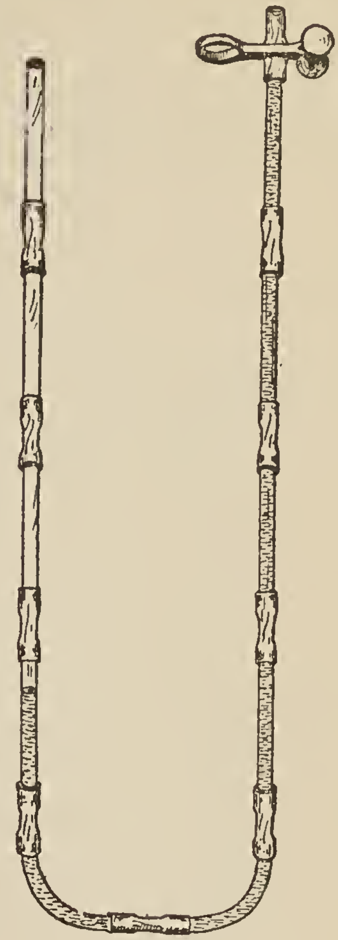


Fig. 52.—Showing That the Atmosphere Exerts Pressure.

EXPERIMENT No. 18

To show that the atmosphere will support a column of water.

Arrange the apparatus as in (1) Fig. 53, fill the tube with water, close one end with a clip and hold both ends in the position illustrated. Does the water remain in the tube? It remains because the pressure of the atmosphere downward on the water in the open tube supports the column of water in the long tube.

Turn the open end sidewise and then downward. Does the water remain in the tube? It remains because the atmosphere exerts pressure sidewise and upward and supports the water.

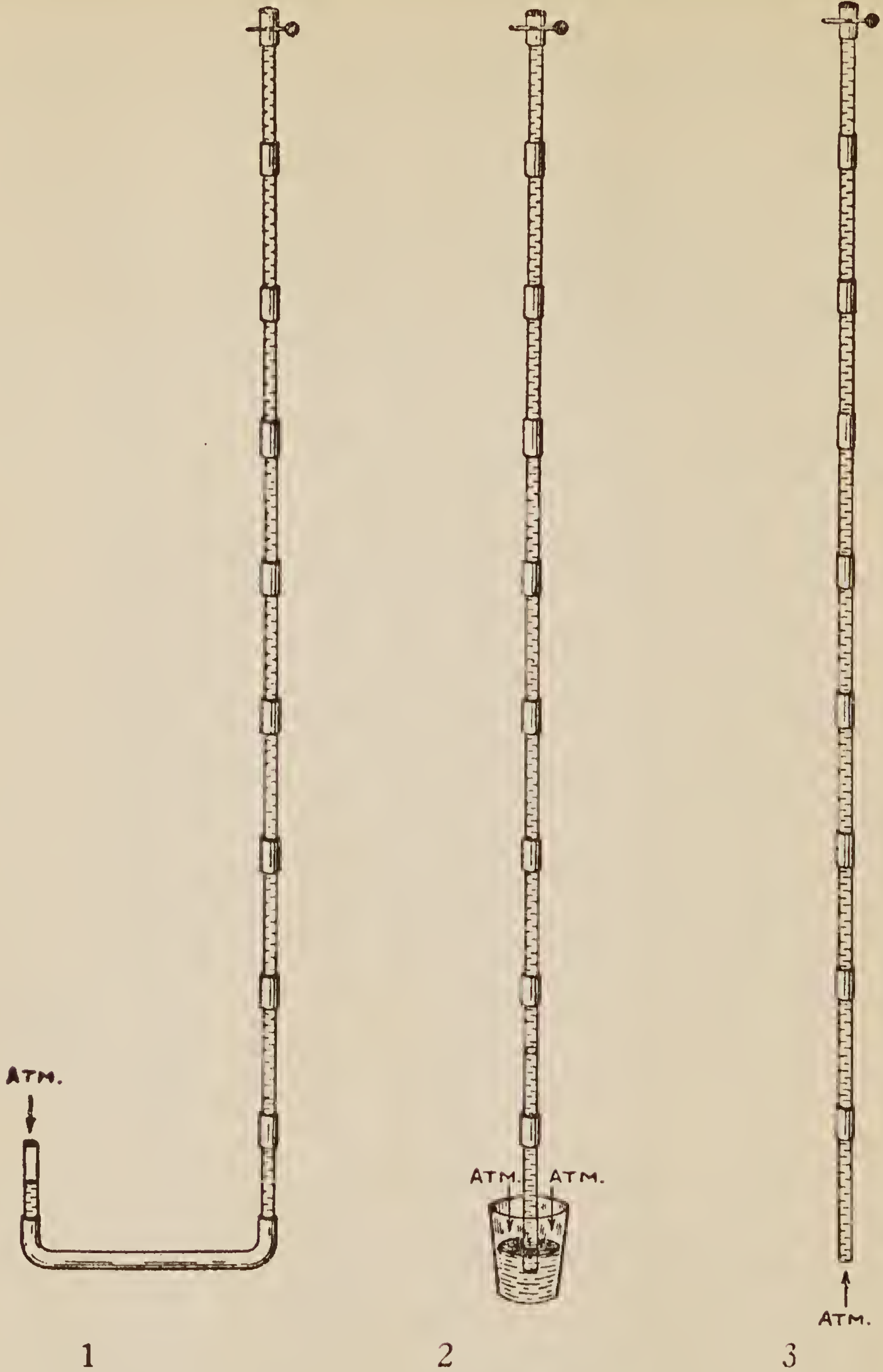


Fig. 53.—Showing That the Atmosphere Will Support Water.

Arrange the apparatus as shown in (2) Fig. 53. Place the lower end of the tube in a tumbler of water, stand on a chair, and suck the air out of the tube, then close the upper end.

Does the water remain? It remains because the pressure of the atmosphere downward on the water in the tumbler supports the water in the tube.

Lift the tube out of the tumbler, (3) Fig. 53, and the water will remain in the tube because it is supported by the upward pressure of the atmosphere. This is possible only with very narrow tubes. The tube you have used in these experiments is about 6 feet long and you have shown that the atmosphere will support a column of water 6 feet high. If you had a tube of sufficient length you could show that the atmosphere will support a column of water 34 feet high, but no more.

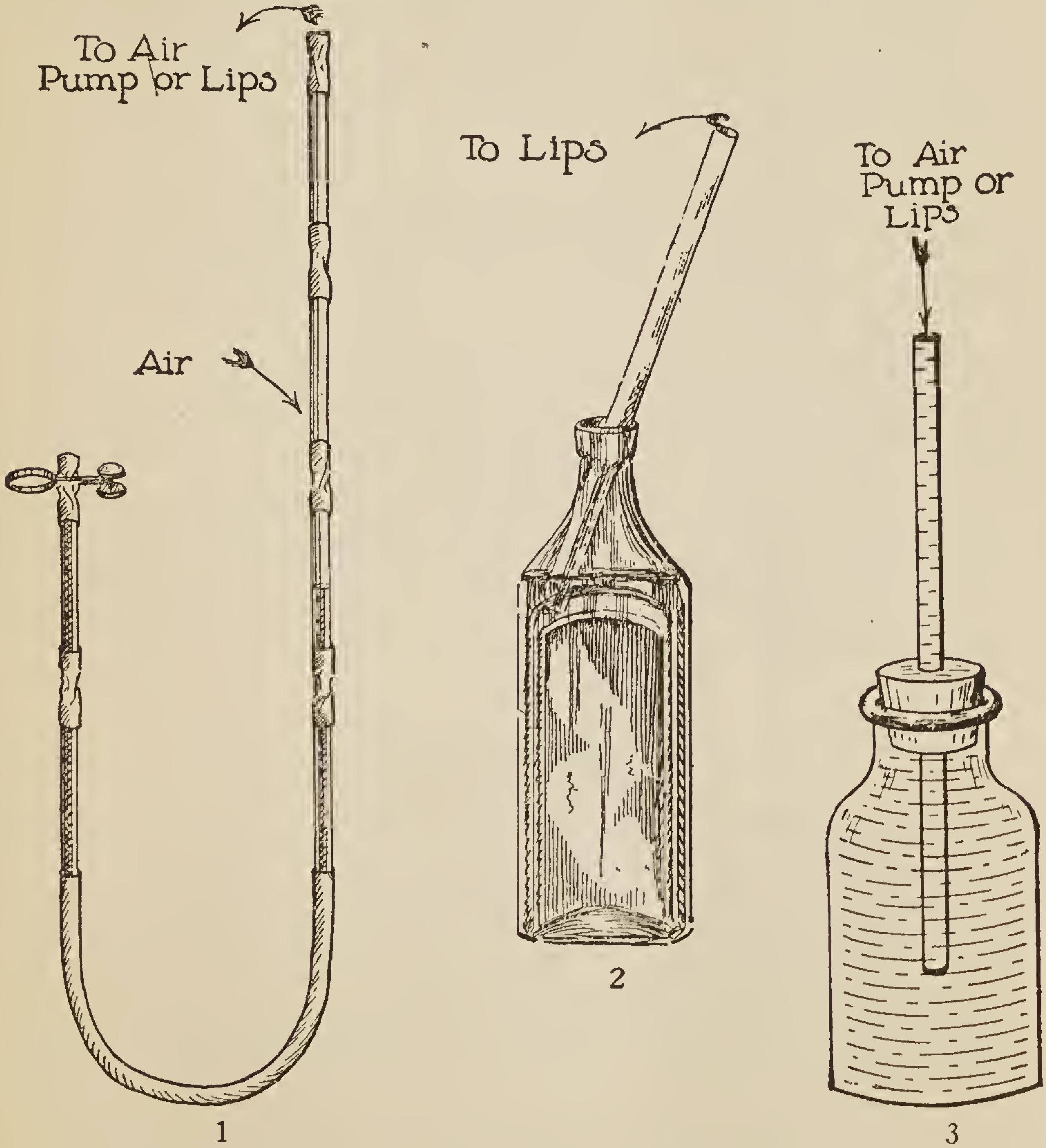


Fig. 54.—Proving That it is the Atmosphere Which Lifts the Water.

EXPERIMENT No. 19

To prove that it is the pressure of the atmosphere which lifts the water.

Make a U tube (1) Fig. 54, with four tubes on one side and two on the other, fill it half full of water so that the two tubes on the short side are quite full, then close the top of this side with a coupling and clip. Now suck the air out of the long side. Do you observe that the water does **not** move?

It does not move because although you have decreased the air pressure in the long side, the atmosphere cannot get at the water in the short side to force it down.

Open the top and repeat the experiment. Does the water move?

To show this in another way. Fill a bottle (2) with water, place a glass tube in it and suck the air out of the tube. You observe that when you remove the air pressure from the water in the tube, the atmospheric pressure on the water in the bottle forces the water up into your mouth.

Now fill the bottle quite full to exclude the air, and close it with a one hole rubber stopper which has one glass tube stuck in the under side and another in the upper side, (3). Suck the air out of the upper tube. Do you find that the water does **not** rise?

It does not rise because although you have decreased the air pressure in the upper tube, the atmosphere cannot get at the water in the bottle to force it into your mouth.

You have proved here that it is the pressure of the atmosphere which lifts the water.

EXPERIMENT No. 20

To show in other ways that the atmosphere exerts pressure downward and upward.

Fill the bottle with water, close the top with the hand, invert the bottle in a pail of water, and remove the hand under water, (1) Fig. 55.

The downward pressure of the atmosphere on the water surface in the pail supports the water in the bottle.

Repeat with the tumbler and tube as shown in (2) and (3).

Fill the bottle with water, cover with a piece of paper, hold the paper on with the hand, invert the bottle and remove the hand, (4).

The paper is held on by the upward pressure of the atmosphere.

Repeat this experiment with a tumbler and tube, (5) and (6).

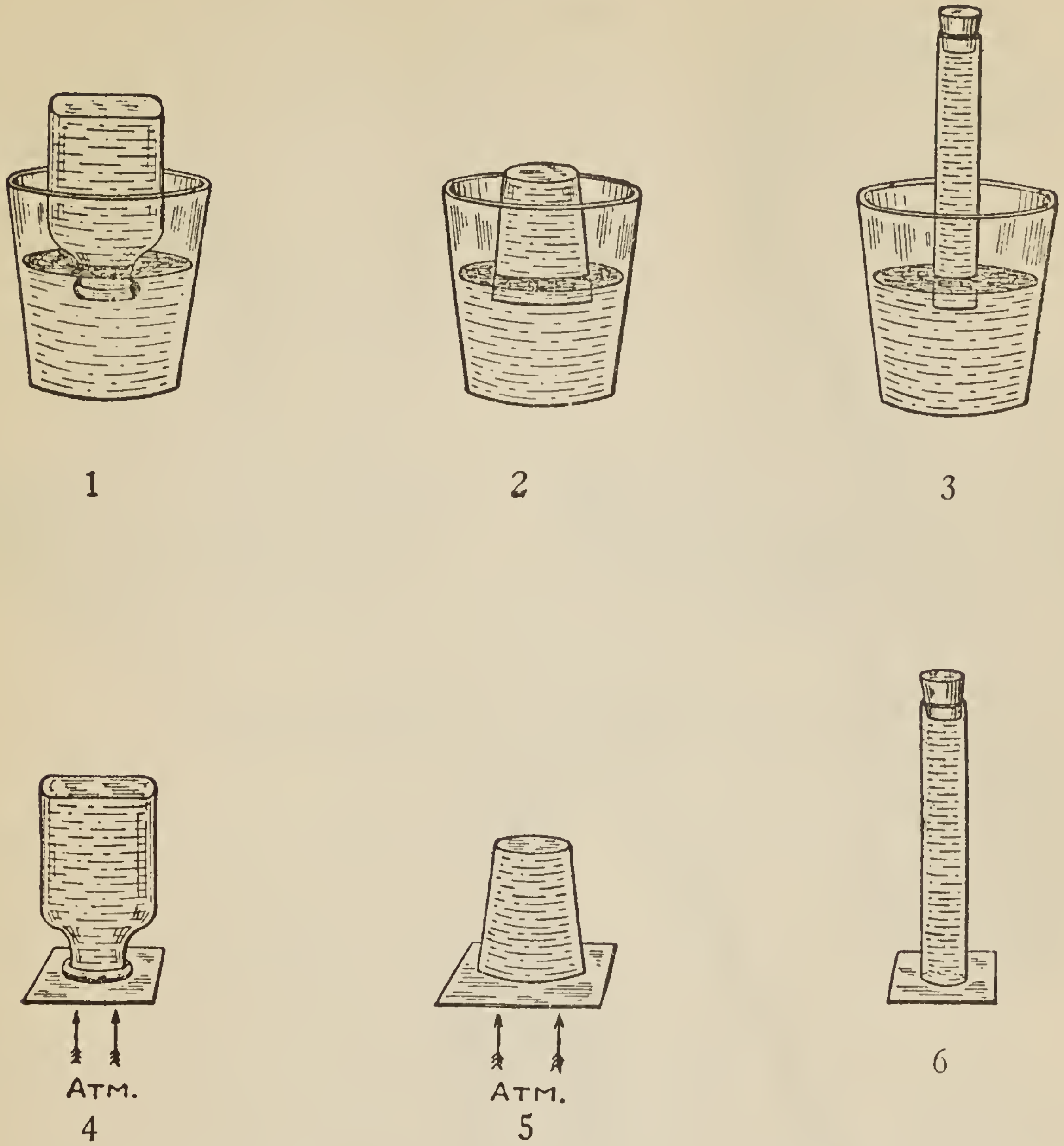


Fig. 55.—Showing That the Atmosphere Exerts Pressure Downward and Upward.

EXPERIMENT No. 21

To illustrate two simple uses of atmospheric pressure.

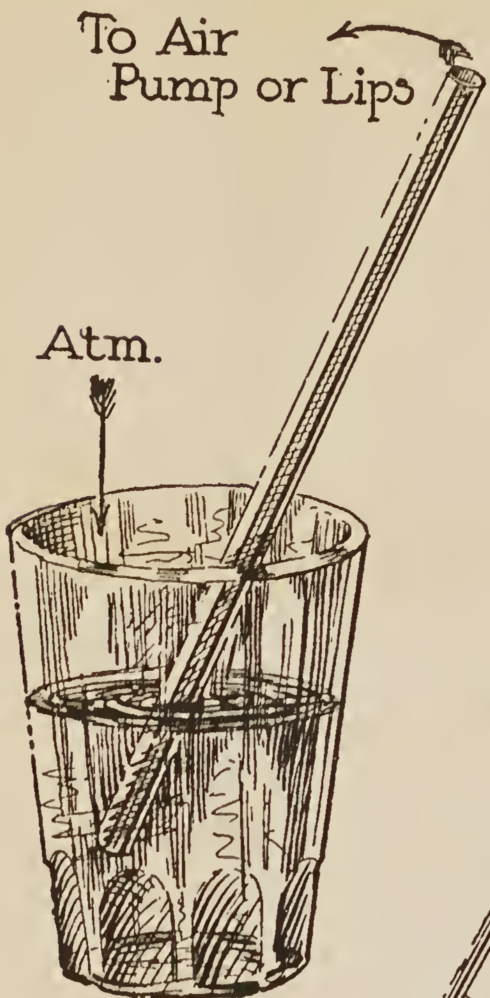
DRINKING SODA WATER

When you drink soda water through a straw or glass tube, (1) Fig. 56, you simply produce a vacuum in your mouth and it is the atmosphere which forces the soda water into your mouth.

Illustrate this with the apparatus, (2) Fig. 56 in which the bottle represents your mouth. Suck air out of the bottle, close clip 1, and open clip 2.

Does the atmosphere force water into the bottle? It forces soda water into your mouth in the same way.

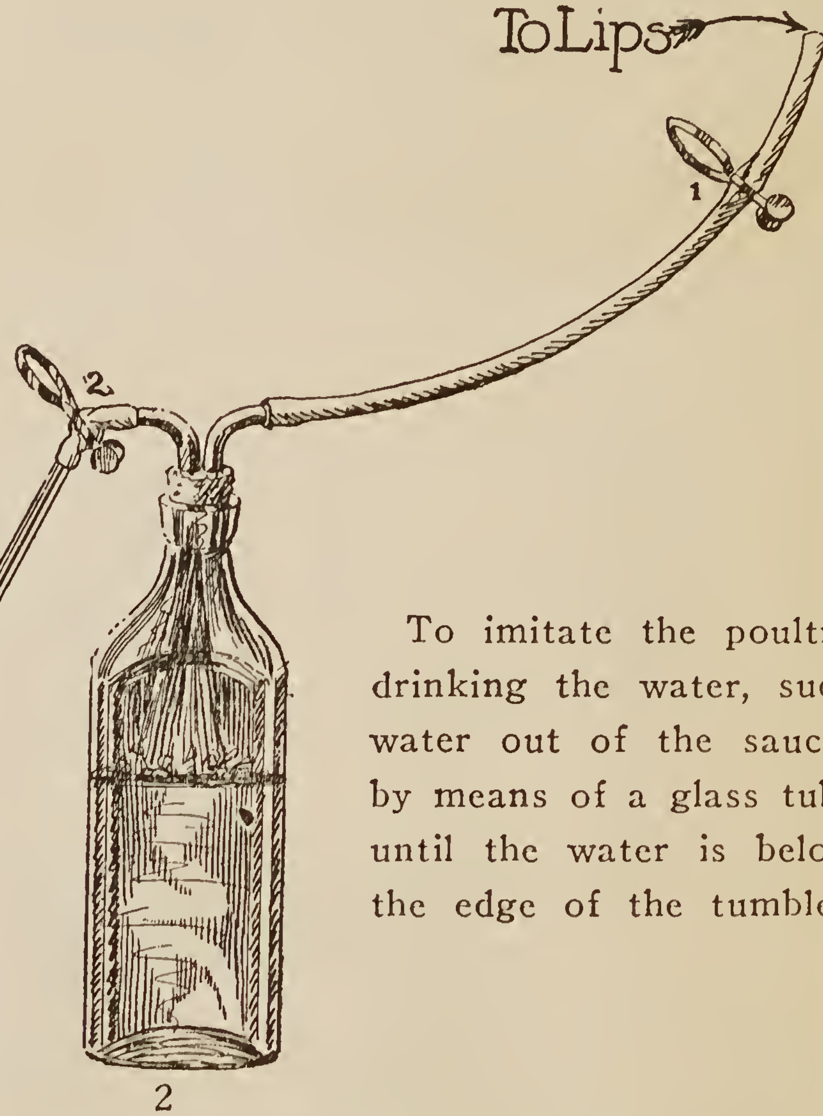
POULTRY DRINKING FOUNTAINS



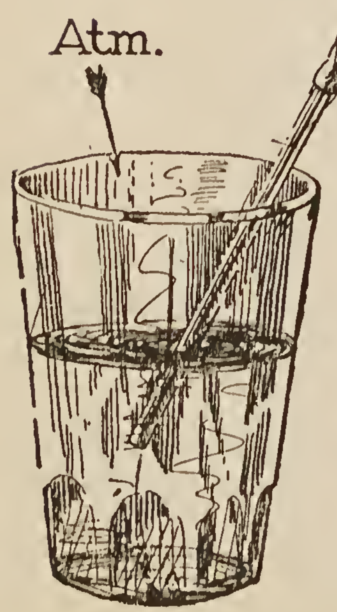
Fill a tumbler with water, place two pieces of lead pencil across the top, cover with a saucer, and invert tumbler and saucer, (1) Fig. 57.

Repeat with the glass bottle, (2).

Does the water run out only until the edge of the tumbler or bottle is covered?



To imitate the poultry drinking the water, suck water out of the saucer by means of a glass tube until the water is below the edge of the tumbler.



Does air enter and water run out only until the edge is again covered?

The atmosphere supports the water.

Note: The atmosphere could support the water in a fountain 34 feet high but no higher.

Fig. 56.—Drinking Soda Water.

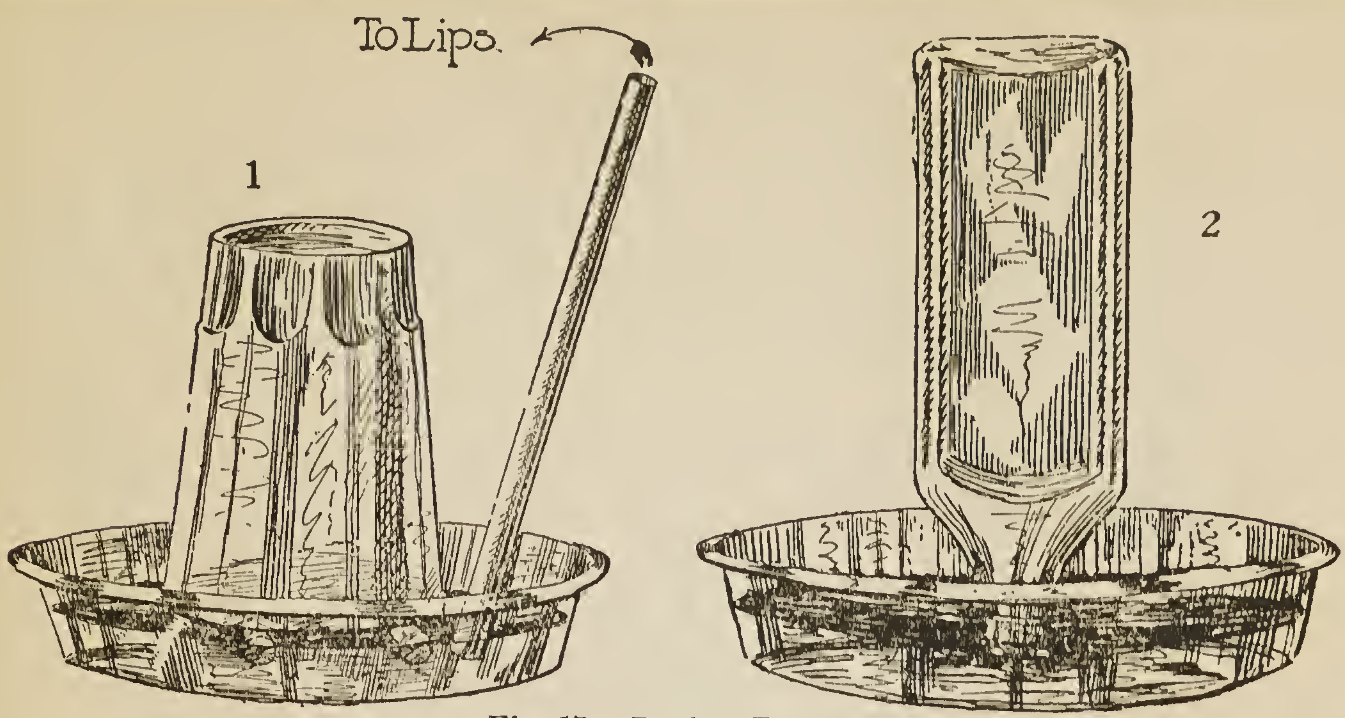


Fig. 57.—Poultry Fountain.

THE SIPHON (Continued)

THE "WHY" OF THE SIPHON

The reason "why" water flows through a siphon is as follows: Suppose, for example, you have a siphon, Fig. 58, closed at the top with a clip. The atmospheric pressure on the water in the right hand tumbler supports only 1 foot of water, while in the left hand tumbler it supports two feet of water.

Now the atmospheric pressure on each is equal to the pressure of a column of water 34 feet high, therefore at the top of the siphon the pressure:
at the right of the clip is

$34 - 1 = 33$ feet of water;

at the left of the clip is

$34 - 2 = 32$ feet of water.

The pressure at the right is greater than that at the left and if the clip is opened the water flows from right to left, that is, from the upper tumbler to the lower tumbler.

This is the "why" of the siphon.

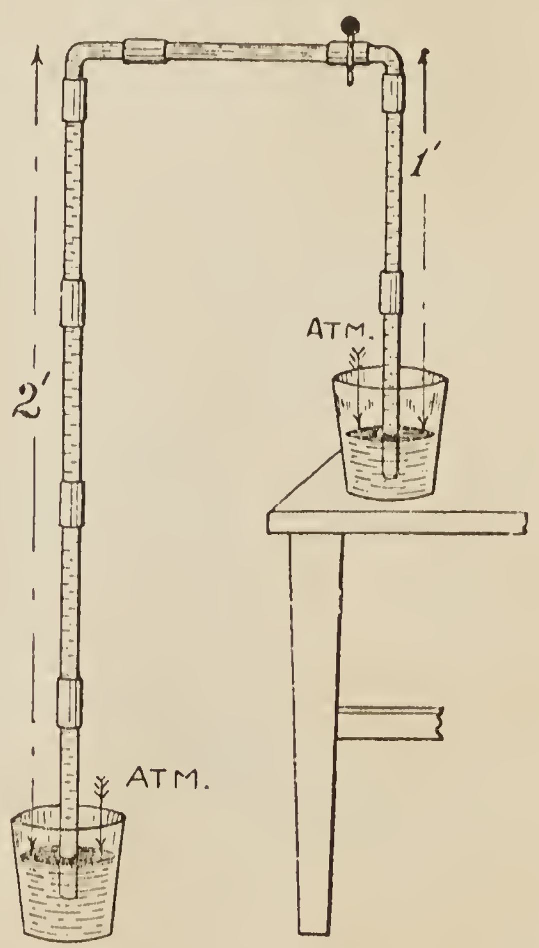


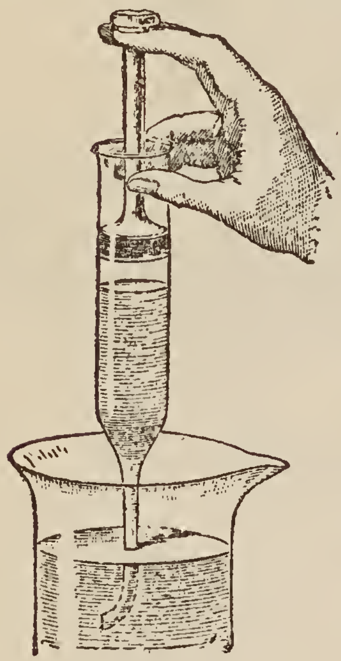
Fig. 58.—Showing Why the Atmosphere Drives Water Through a Siphon

PUMPS

EXPERIMENT No. 22

To illustrate the action of a syringe.

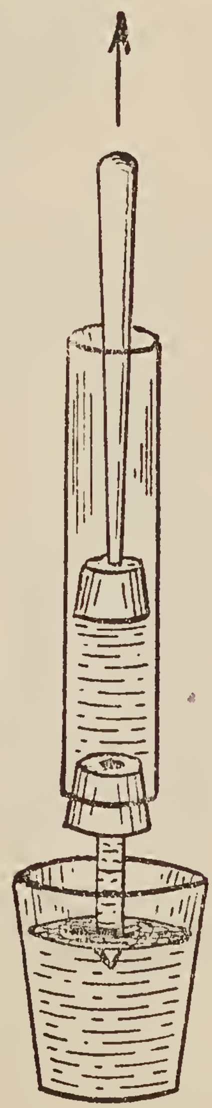
The simplest kind of pump is the syringe, (A) Fig. 59. When you lift the plunger, there is a vacant space or partial vacuum left below the plunger and the atmospheric pressure on the water in the tumbler lifts water into the syringe.



A

Courtesy of The MacMillan Co.

Illustrate this by means of the syringe, (B) Fig. 59. Soap the plunger to make it slippery, fill the syringe, lift the nozzle end and squirt the water out, (C) Fig. 59.



B

Fig. 59.— The Syringe

C

WATER GUN SHOOTING

GAME No. 6

The syringe makes a fine water gun. Use it as follows:

(1) Put up a bent piece of cardboard as a target and try to hit it from various distances, (A) Fig. 60.

(2) See who can send the stream to the greatest height.

(3) See who can send the stream to the greatest distance.

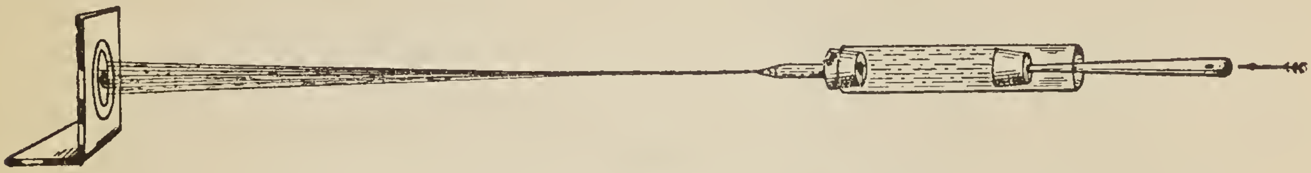


Fig. 60 A.—Water Gun Shooting and Big Gun Battle.

BIG GUN BATTLE

GAME No. 7

Each player here puts up the same number of lead or paper soldiers and at a given signal each starts to knock down the enemy soldiers with his water gun which here represents a large caliber gun firing shells, (B), Fig. 60.

The winner is the one who first knocks down all the enemy soldiers.

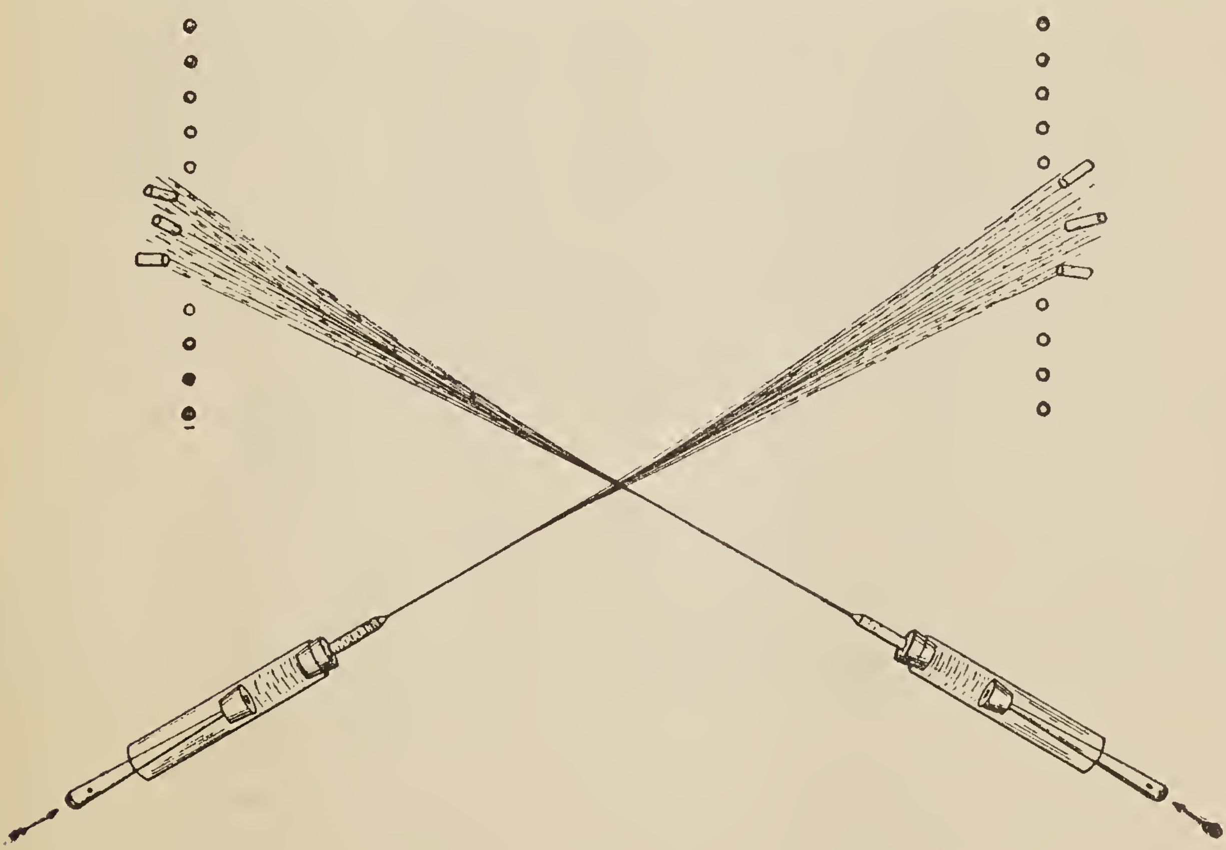


Fig. 60 B.—Water Gun Shooting and Big Gun Battle.

MACHINE GUN BATTLE

GAME No. 8

Each player is behind a barricade which represents a trench (A), Fig. 61 and is armed with a syringe which here represents a machine gun. The rules about wounded and killed are the same as in Game No. 2. The winning side is the one which first kills all the enemy.

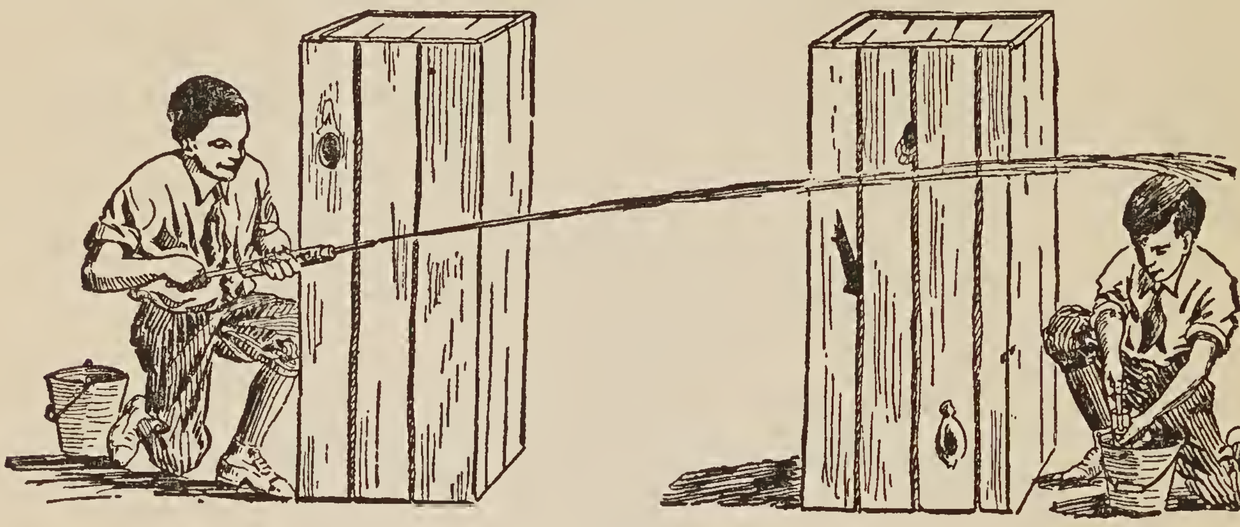


Fig. 61 A.—Machine Gun Battle.

THE DIABLO WHISTLE

GAME No. 9

The apparatus, Fig. 61 B makes a most uncanny whistle when you blow into it as illustrated and move the plunger up and down.

The game is: (1) to make the most diabolical sound you can; (2) to play the eight notes of an octave as well as you can; (3) to play a tune if you can.

Fig. 61 B.—The Diablo Whistle.

THE LIFT PUMP

Common pumps are of two kinds: lift pumps, Figs. 62, 63, which lift water only to the spout; and force pumps, Fig. 65, which force the water to any height above the spout. Both types of pumps have two valves which open upward.

The Lift Pump, Fig. 62, has one valve S at the bottom of the barrel C and another V in the plunger P. The atmospheric pressure lifts water from the well into the pump through the suction pipe T.

The way the lift pump lifts water is illustrated in drawings 1 to 6, Fig. 63.

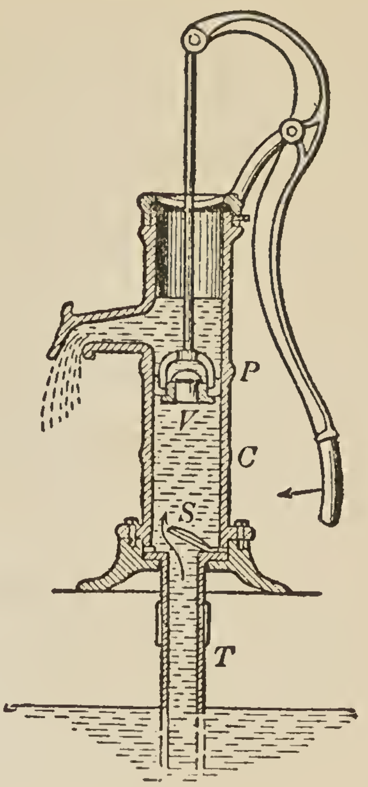


Fig. 62.—A Lift Pump.
Courtesy of The MacMillan Co.

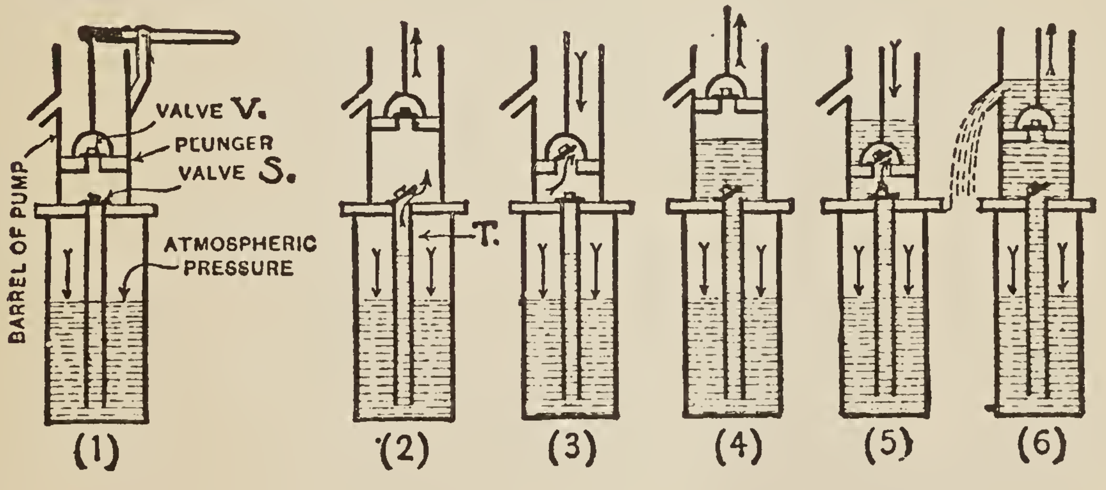


Fig. 63.—Showing How a Pump Raises Water.
Courtesy of The MacMillan Co.

Before the pump is started the condition is that shown in (1): both valves are closed and the water level in the suction pipe is the same as that in the well.

When the plunger is raised as in (2), the air in the barrel beneath the plunger is given more room, it expands and its pressure on the valve S is decreased; the air in the suction pipe then lifts the valve S and part

of it expands into the barrel; this decreases the air pressure on the water in the suction pipe, and the atmospheric pressure on the water in the well forces some water into the suction pipe.

When the plunger is shoved down as in (3), valve S closes and the air in the barrel is forced up through the plunger valve V.

When the plunger is raised again as in (4), the operations explained in (2) take place again, and the atmospheric pressure on the water in the well forces more water into the suction pipe and also into the barrel.

When the plunger is shoved down again as in (5), valve S closes again and all the air in the barrel, with part of the water, is forced up through the plunger valve V.

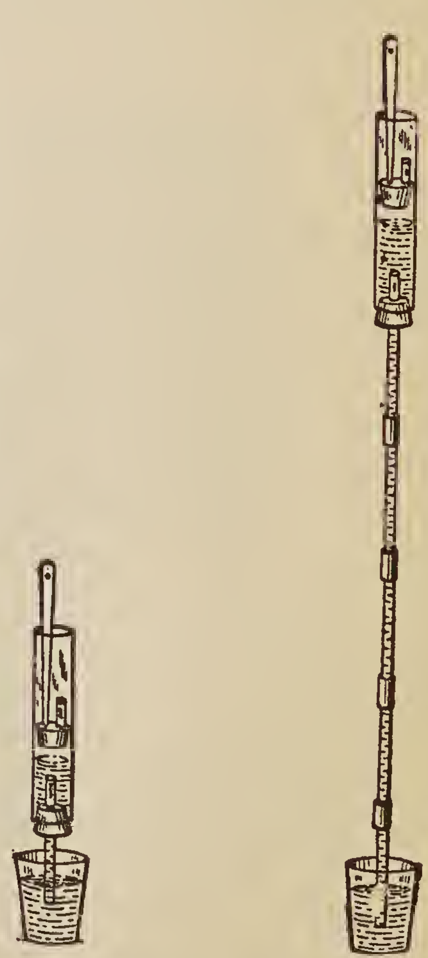
When the plunger is raised again as in (6), the water above the plunger is lifted to the spout and the atmospheric pressure on the water in the well forces more water into the suction pipe and barrel. After this (5) and (6) are repeated as long as the plunger is operated.

EXPERIMENT No. 23

To make and operate a Lift Pump.

Arrange the apparatus as shown in (1) Fig. 64. Soap the plunger, place the lower end of the narrow tube in a glass of water, and move the plunger up and down slowly.

Do you find that: on the up stroke of the plunger, water moves up through the narrow tube and lower valve into the pump barrel; and on the down stroke, the water remains at the same height because the lower valve closes, but as the plunger moves down, the air and water pass through the plunger valve? Do you notice that on the succeeding up strokes, water rises and flows over the top, and on succeeding down strokes it moves through the plunger valve?



1 2
Fig. 64.—The Lift Pump.

Attach three or four narrow tubes below the pump barrel to make the suction pipe longer, (2) Fig. 64, and repeat the experiment.

Attach all the narrow tubes and the rubber tube to the pump barrel and repeat the experiment.

Do you find that the atmospheric pressure on the water in the tumbler lifts the water into the pump barrel when you move the plunger up?

The pressure of the atmosphere is equal to the pressure of a column of water 34 feet high and no more, therefore, a pump must be placed at a less height than 34 feet above the water it is pumping and in practice the height is usually 25 feet or less.

THE FORCE PUMP

The force pump, Fig. 65, has a valve A at the bottom of the barrel, but the plunger V is solid, the discharge pipe leaves the barrel below the plunger, and the second valve B is below an air chamber at one side; also the top of the barrel is closed by an inverted U shaped leather ring which surrounds the plunger and prevents the water from escaping.

It pumps water in exactly the same way as does the lift pump.

The ball valves shown here have the advantage that they wear evenly because they turn continuously. Both lift pumps and force pumps can have either ball valves or common flap valves.

The air chamber protects the force pump from excessive strain because the air compresses under excessive pressure; it also tends to keep a steady stream in the discharge pipe because the compressed air continues to force the water out of the air chamber while the plunger is making the up stroke.

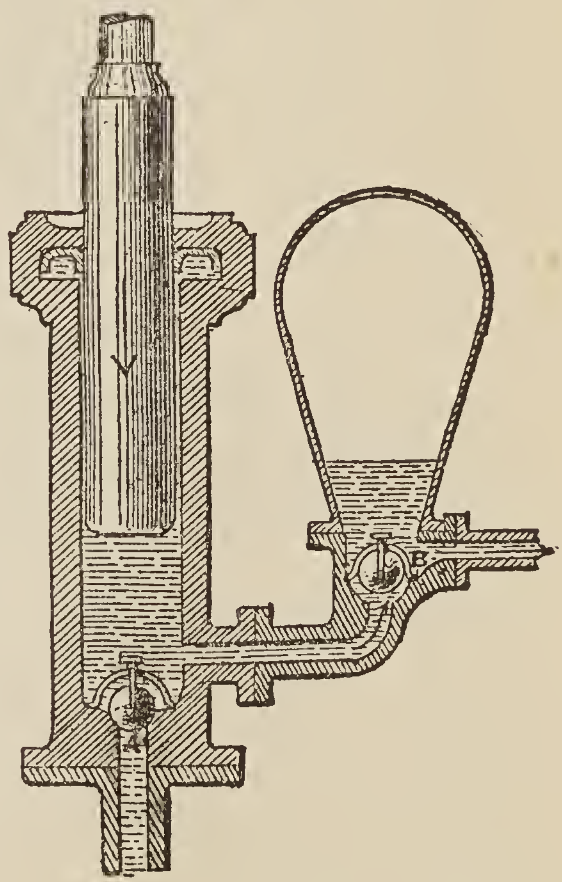
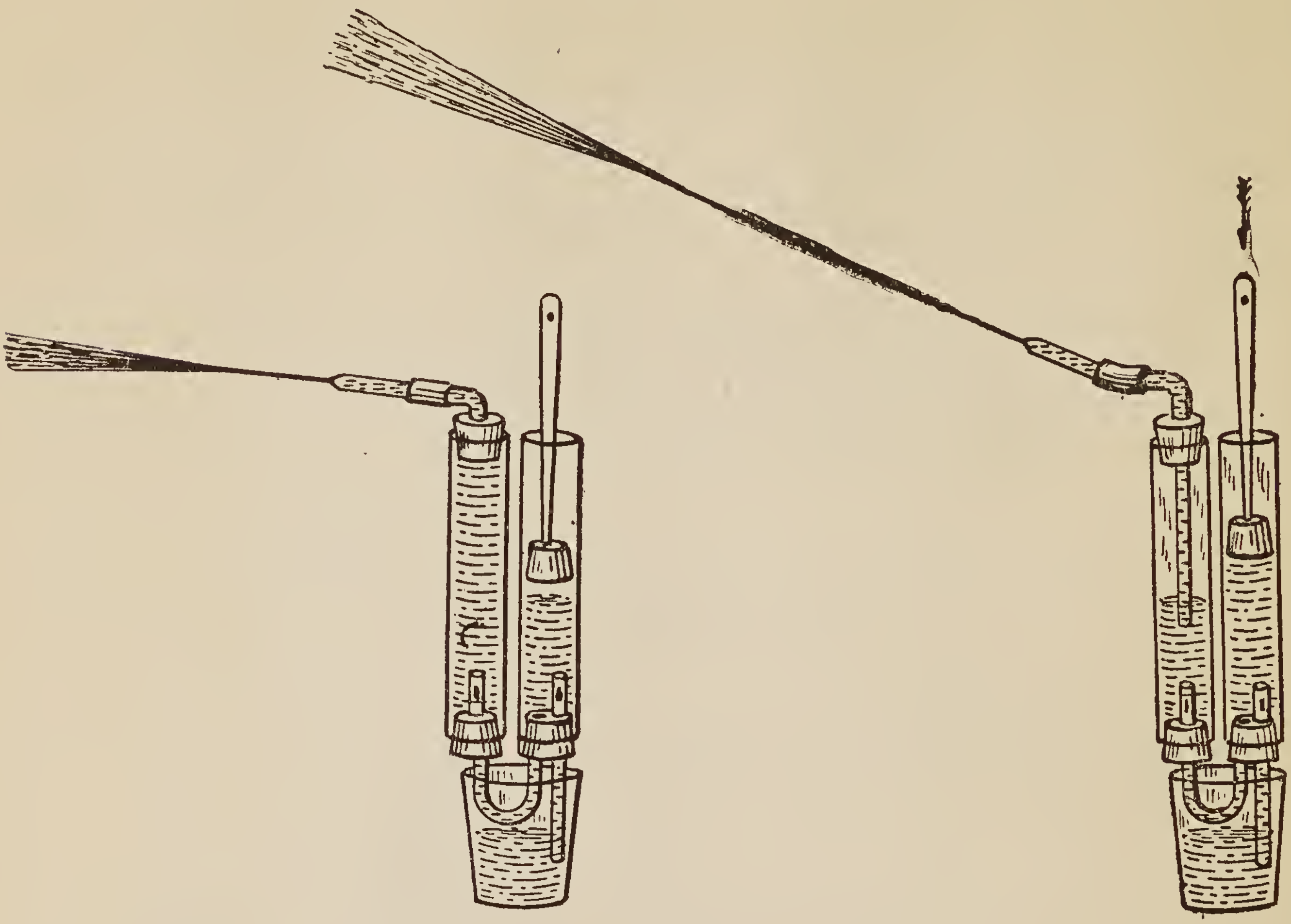


Fig. 65.—Force Pump with Solid Plunger and Ball Valves.
Courtesy of the MacMillan Co.



1 2

Fig. 66.—The Force Pump.

EXPERIMENT No. 24

To make and operate a Force Pump.

Arrange the apparatus as shown in (1), Fig. 66. Soap the plunger, place the suction pipe in a tumbler of water, pour a little water above the plunger to make sure it is air tight; and move the plunger up and down.

Do you observe that on the up stroke water enters the barrel through the valve, and that on the down stroke it is forced into the side tube through its valve? If the valves are not quite air tight pour water into both tubes to cover them.

Make an air chamber in the side tube by inserting a short narrow glass tube below the upper stopper, (2), Fig. 66.

Operate the force pump.

Do you observe that the air is slightly compressed in this chamber, on the down stroke of the plunger, and that this compressed air keeps the water flowing for a short time after the stroke is finished.

Repeat the experiment using short quick strokes of the plunger.

Do you find that you can keep a fairly steady stream issuing from the nozzle?

Water can be forced to any height in the discharge pipe of a force pump but the suction lift should not be more than about 25 feet, that is the pump plunger must be within 25 feet vertically of the water it is pumping.

EXPERIMENT NO 25

To show how water is pumped into an elevated tank.

A lift pump can be used to pump water into an elevated tank only if the top of the tank is not over 25 feet (34 feet theoretically) above the water in the well. If the tank is higher than this, a force pump must be used.

Illustrate this use of a force pump by means of the apparatus shown in Fig. 67. Pump water into the tank and then draw off some through the faucet below. This equipment represents a complete water supply system.

FORCE PUMP CONTEST

GAME No. 10

The game here is to see who can force the water to the greatest height and to the greatest distance. Tie the stoppers in with cord and stretched rubber bands. Use the apparatus shown in (2) Fig. 66.

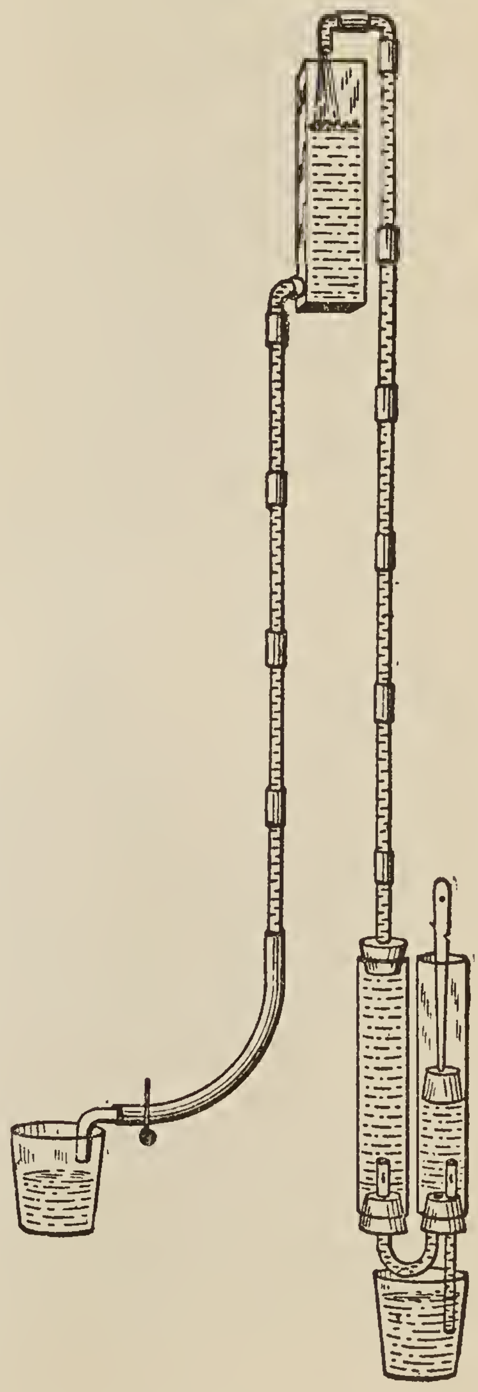
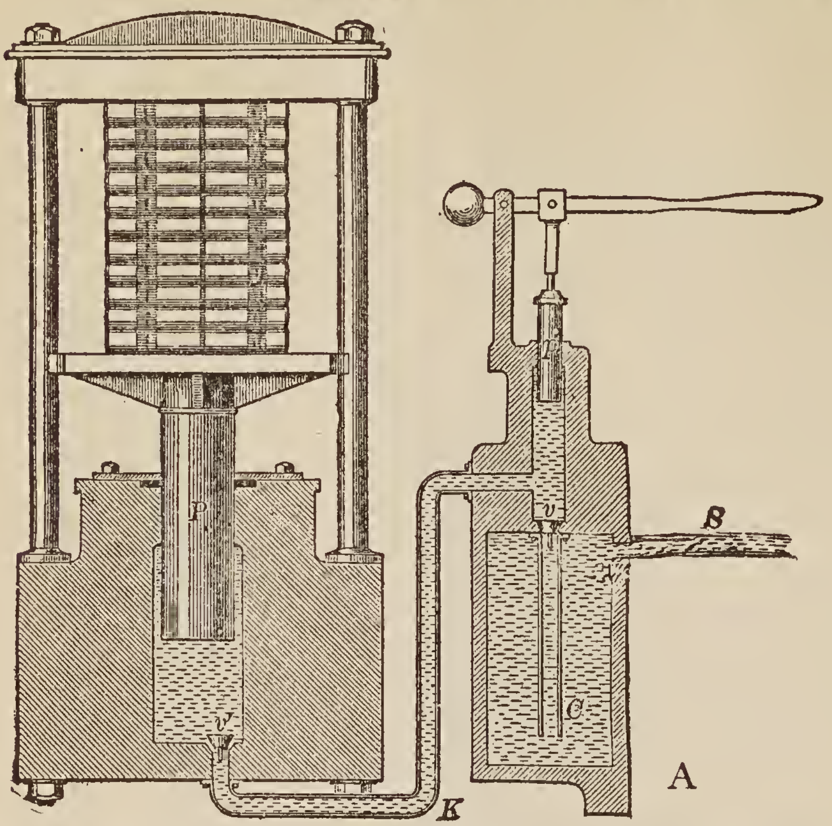
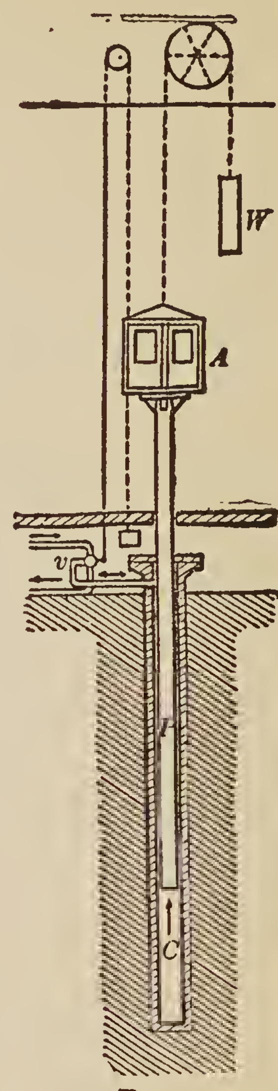


Fig. 67.—Pump Water into an Elevated Tank with a Force Pump.

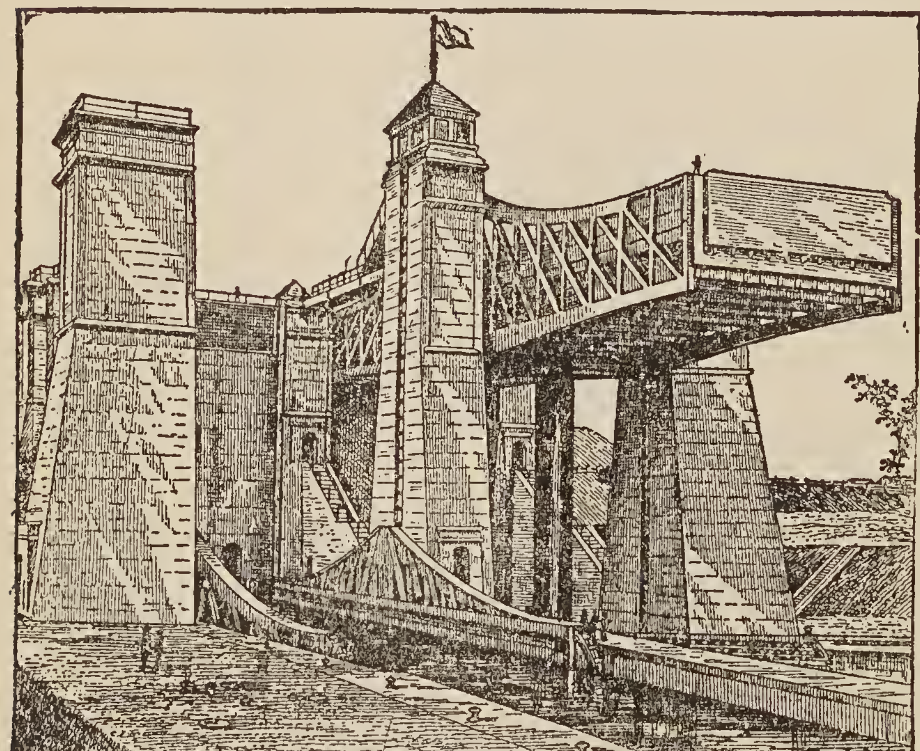
HYDRAULIC APPLIANCES



A



B

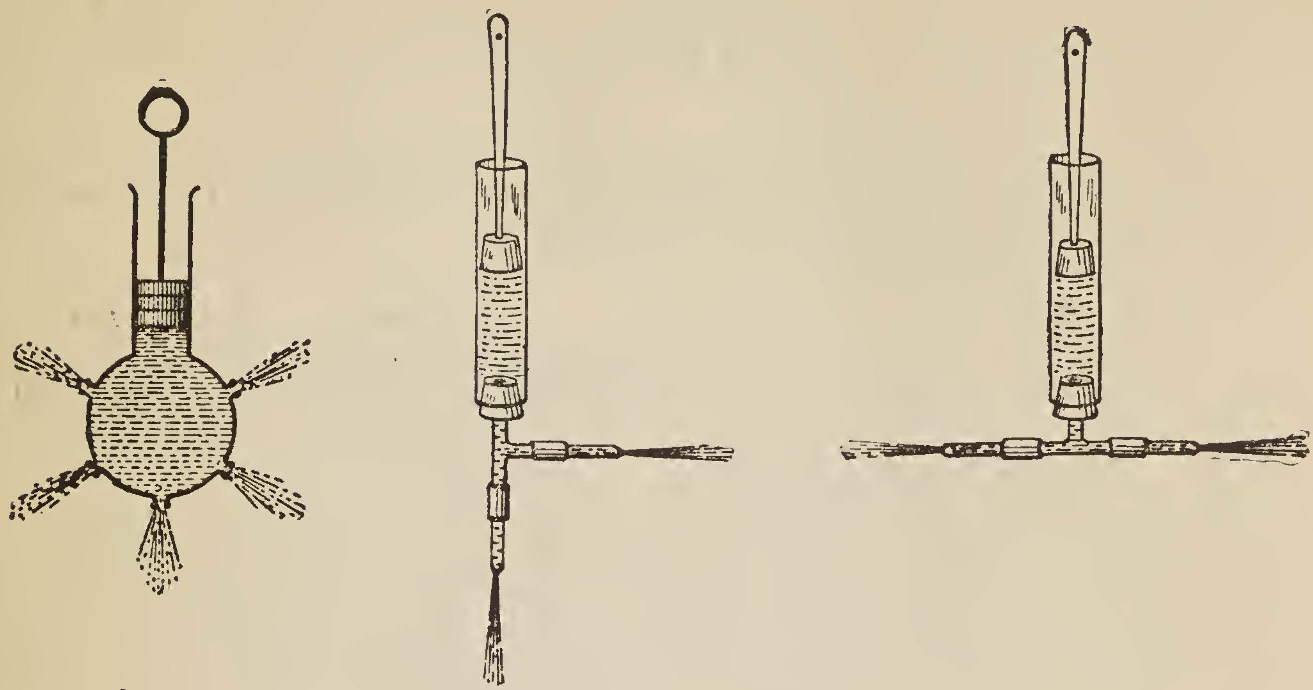


C

The hydraulic press (A), hydraulic elevator (B), and hydraulic lift lock (C), Fig. 68, are each operated by means of pressure exerted on water, and in order to understand them you will first illustrate Pascal's law which tells how pressure is transmitted by water.

Fig. 68.—Hydraulic Press, Elevator and Lift Lock.
A—Courtesy Ginn & Co. *B—Courtesy of The MacMillan Co.*
C—From "Ontario High School Physics" by Permission of the Publishers

PASCAL'S LAW



1 2 3

Fig. 69.—Illustrating Pascal's Law.

Pascal's Law is: Pressure exerted on a liquid is transmitted equally and undiminished in all directions.

This law is usually illustrated by means of the apparatus shown in (1) Fig. 69. It is a syringe with a glass bulb which has five nozzles of the same size and in the same plane. When the syringe, filled with water, is held with the nozzles horizontal and the plunger is forced in, the streams which issue from the nozzles are of exactly the same length. This shows that pressure exerted on water is transmitted equally in all directions. This is very surprising because since the plunger exerts the pressure in the direction of the front stream we might expect this stream to be the longest: we find, however, that they all have the same length.

EXPERIMENT No. 26

To show that pressure on water is transmitted equally in all directions.

Use the apparatus (2) Fig. 69. Fill the tube with water, insert the plunger, hold the nozzles horizontal, and force the plunger in steadily. Are the streams of equal length?

Repeat with the apparatus (3) Fig. 69.

With (2) Fig. 69 you show that the pressure is transmitted equally forward and sidewise, and with (3) Fig. 69, that it is transmitted equally in both sidewise directions.

This experiment shows that water transmits pressure equally in all directions. The experiments described below show that it transmits it equally and **undiminished** in all directions.

The two cylinders and connecting pipe, Fig. 70, are filled with water and each cylinder is fitted with a water tight piston; the area of cross section of the small piston is 1 sq. in. and of the large piston, 100 sq. in. If now a pressure of 1 ℔ is exerted on the small piston, it is found that this pressure is transmitted equally and undiminished by the water, and that therefore, the upward pressure on the large piston is 1 ℔. on each sq. in. or the total pressure upward is 100 ℔s. That is, 1 ℔. on the small piston supports 100 ℔s. on the large piston.

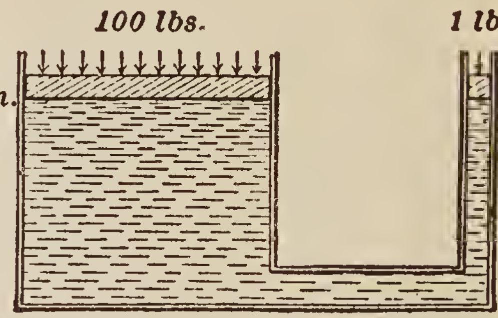


Fig. 70.—A Pressure of One Pound on a Small Piston Exerts a Lift of One Hundred Pounds on a Large Piston.
Courtesy of The MacMillan Co.

This is very surprising and it looks as if we were getting something for nothing. This is not so, however, because if the small piston is moved down 1 inch, the large piston moves up only 1/100 of an inch. That is, "what is gained in force is lost in distance moved."

The hydrostatic bellows, Fig. 71, is an apparatus of this kind and it illustrates Pascal's law beautifully. It consists of two disks of wood connected by a water-proof canvas cylinder to make a collapsible drum. A small pipe passes through the lower disk and opens into the drum.

If now the drum is filled with water and a man stands on the upper disk, it is found that a very small amount of water, AB, in the pipe will support his weight.

Fig. 71.—The Hydrostatic Bellows. The Small Amount of Water, AB, Supports a Man's Weight.
Courtesy of The MacMillan Co.

This is very striking and it is explained as above. If, for example, the area of the pipe is 1 sq. in. and that of the disk is 500 sq. in. then 1 ℔. of water in AB will support a weight of 500 ℔s. on the disk. Similarly ½ ℔. of water in AB will support ½ x 500 = 250 ℔s. on the disk, or ¼ ℔s. of water in AB will support ¼ x 500 = 125 ℔s. on the disk, and so on.

EXPERIMENT No. 27

To make and operate a hydrostatic bellows.

Arrange the apparatus as shown in Fig. 72. Place the book on the empty observation balloon, and fill the balloon with water until it is about half full. Do you observe that a very little water in the tube supports the weight of one end of the book.

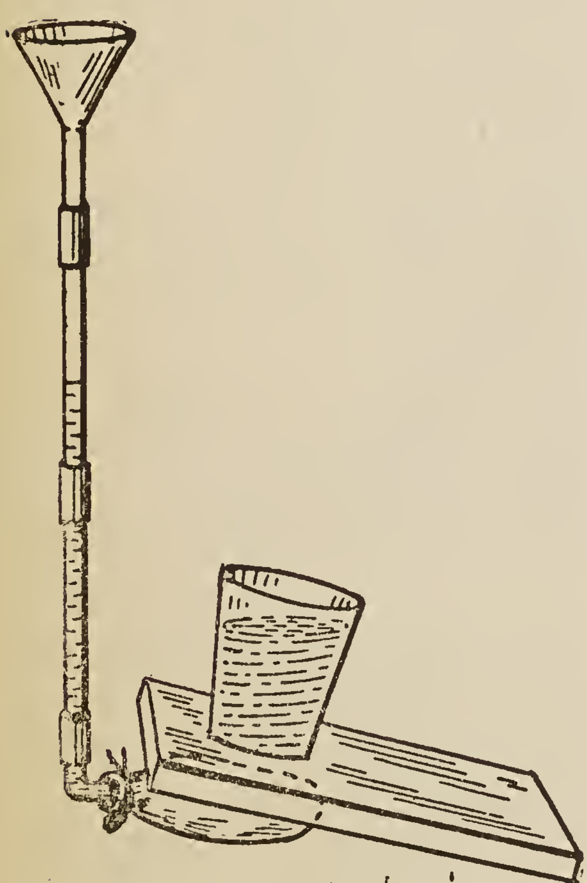


Fig. 72.—Illustrating the Hydrostatic Bellows.

Place an empty tumbler on the book and fill it with water. Do you find that a small extra amount of water in the tube supports the glass of water?

Remove the tumbler and press down on the book with your hand. Do you find that to lift water in the tube you must exert a force much greater than the weight of this water.

These experiments are certainly very striking and they illustrate Pascal's law as follows: The weight of the extra water in the tube exerts pressure downward on an area equal to that of the inside of the tube; this pressure is transmitted **equally** and **undiminished** in all directions by the water, and is exerted against each equal area of the inside of the balloon.

THE HYDRAULIC PRESS

The hydraulic press is an application of Pascal's law and of the hydrostatic bellows. It is used where great pressure is required, for example, to compress merchandise, to bend ship plates, to lift great weights, and so on.

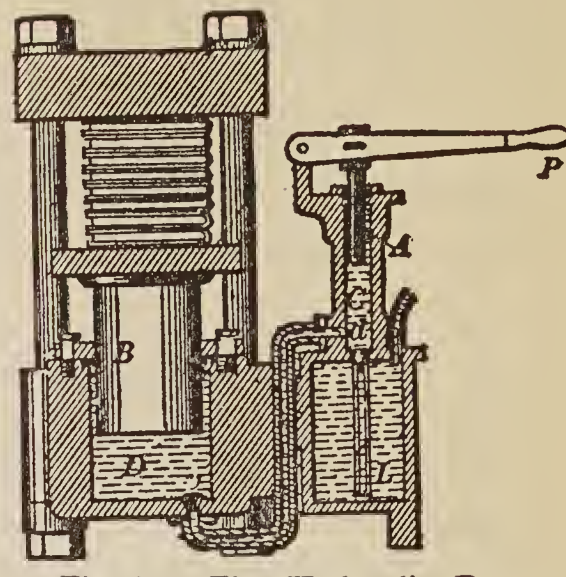


Fig. 73.—The Hydraulic Press.
Courtesy of The MacMillan Co.

The press has a force pump with handle P which operates the small piston A in the small cylinder C and pumps water from the reservoir L through the valve d, through the connecting pipe and valve v, and into the large cylinder D. The large piston B, or ram as it is called, moves up and down in D. Both A and B have collars which prevent the escape of water.

If now the end of ram B has an area 100 times as great as the end of A, then each 1 ℔. exerted on A exerts a lift of 100 ℔s. on B, and so on.

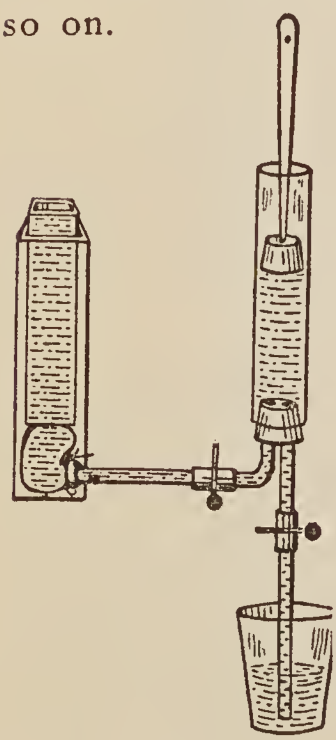


Fig. 74.—Illustrating the Working of a Hydraulic Press.

EXPERIMENT No. 28

To make and operate a hydraulic press.

Arrange the apparatus as shown in Fig. 74, where the tin can in the tank represents the ram and where the balloon represents the collar of the ram. Soap the plunger to make it slippery.

Open lower clip, raise the plunger, close lower clip, open side clip and lower the plunger. Repeat until the balloon is partly filled with water.

Now fill the tin can with water and repeat the operations above.

Do you find that a small force on the plunger will lift the relatively large weight of the tin can full of water?

You have shown here that on the hydraulic press a small force moving the small piston a long distance lifts a great weight on the large piston a small distance.

THE HYDRAULIC ELEVATOR

The simplest form of hydraulic elevator is illustrated in Fig. 75. The passenger cage *A* is securely fastened to the top of a long ram *P* which moves up and down in a deep cylinder *C*. The elevator is raised by the city water pressure or, if this pressure is not sufficient, by the pressure of water pumped into a tank on the roof of the building. The water enters through the pipe *m* and through the three-way valve *v*, and it leaves through the three-way valve and the lower pipe.

The weight of the cage and ram is partly counterbalanced by the weight shown. When water is admitted to the cylinder, it exerts pressure upward on the bottom of the ram and raises the ram and cage; when the discharge pipe of the cylinder is opened, the cage and ram descend by their own weight and drive the water out of the cylinder.

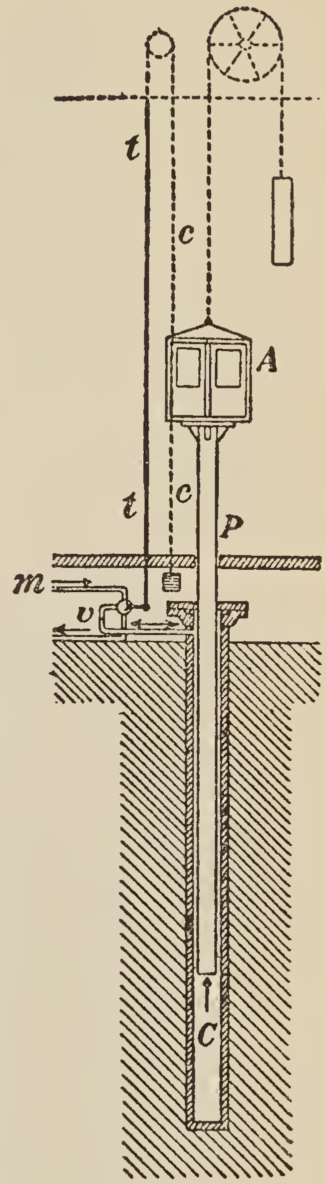


Fig. 75.—The Hydraulic Elevator.

From "Millikan & Gale's First Course in Physics." By Permission of Ginn & Co., Pub.

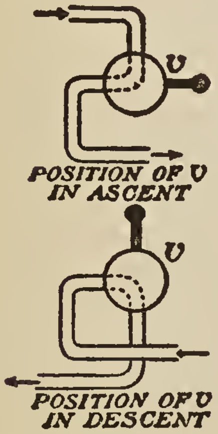


Fig. 76.—The Three-way Valve.

From "Millikan & Gale's First Course in Physics." By Permission of Ginn & Co., Pub.

The operation of the three-way valve is illustrated in Fig. 76. The lever handle is weighted at the end and is operated by the cord t, t, c, c, which passes through the cage. When the operator pulls the cord up the valve takes the upper position, water is admitted to the cylinder, and the ram and cage are raised. When the operator pulls the cord down, the valve takes the lower position and connects the cylinder with the discharge pipe; the cage and ram then descend by their own weight and in doing so force water from the cylinder to the sewer.

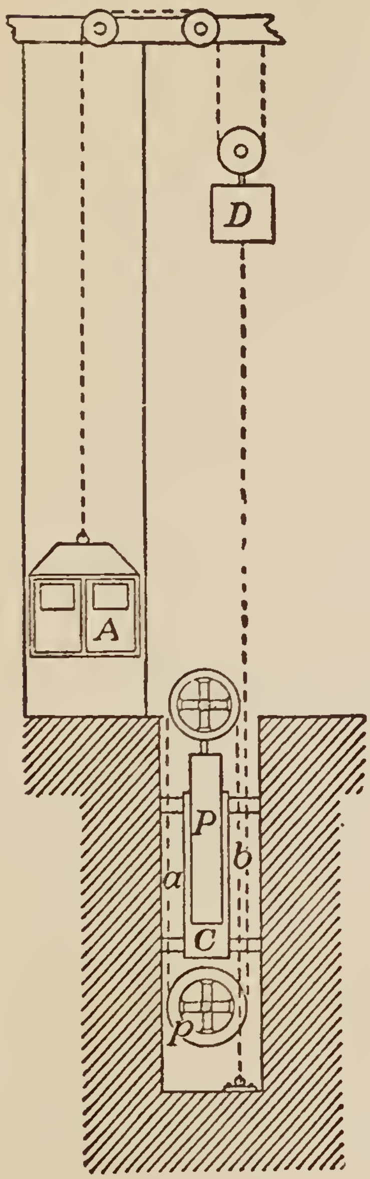


Fig. 77.—A Rapid Hydraulic Elevator for Passengers.
From "Millikan & Gale's First Course in Physics." By permission of Ginn & Co., Publishers

When speed is desired, for example in carrying passengers, the elevator is arranged as shown in Fig. 77. The plunger or ram P moves in a cylinder C. Both ram and cylinder carry a number of large separate pulleys, side by side, around which a steel cable is passed a number of times and then attached to the counterpoise weight D.

If, for example, the steel cable makes 10 loops around the pulleys there are 20 strands between the two sets of pulleys. If then the ram moves 1 foot each strand is lengthened 1 foot and the counterpoise is pulled down 20 feet. Since the cable attached to the passenger cage passes around the pulley of the counterpoise as shown, each foot the counterpoise descends raises the cage 2 feet. Thus if the ram moves 1 foot, the counterpoise moves 20 feet and the cage, 40 feet. This gives the passenger cage a speed forty times that of the ram.

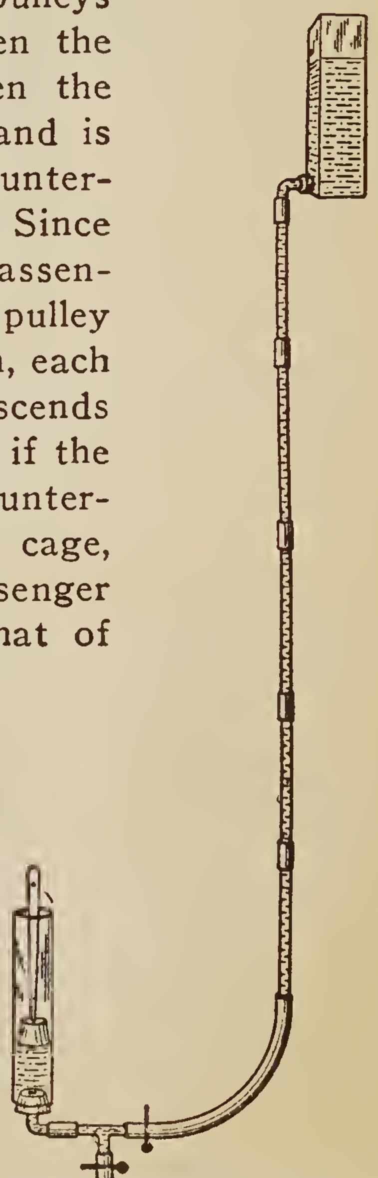


Fig. 78.—Illustrating the Working of a Hydraulic Elevator.

The ram is moved by water from the city mains which is controlled by a three-way valve as described above.

EXPERIMENT No. 29

To make and operate a hydraulic elevator.

Arrange the apparatus as shown in Fig. 78. Soap the plunger well to make it slippery.

Open side clip. Is the cage raised? Close side clip. Does it stop?

Open lower clip and press down gently on the cage. Does it descend? Close lower clip. Does it stop?

Now open and close side clip to raise the cage a short distance at a time. Do you find that you control the elevator perfectly as it rises?

Now open and close lower clip while you force the cage down a short distance at a time. Do you find that you can control the elevator perfectly as it descends and that you cannot move it down when the clip is closed?

You have shown here how the ram and cage of an elevator are raised by water pressure and how they descend by their own weight. You have shown also that you can stop them anywhere, while rising or descending, by closing the proper valve.

HYDRAULIC LIFT LOCKS
CANAL LOCKS

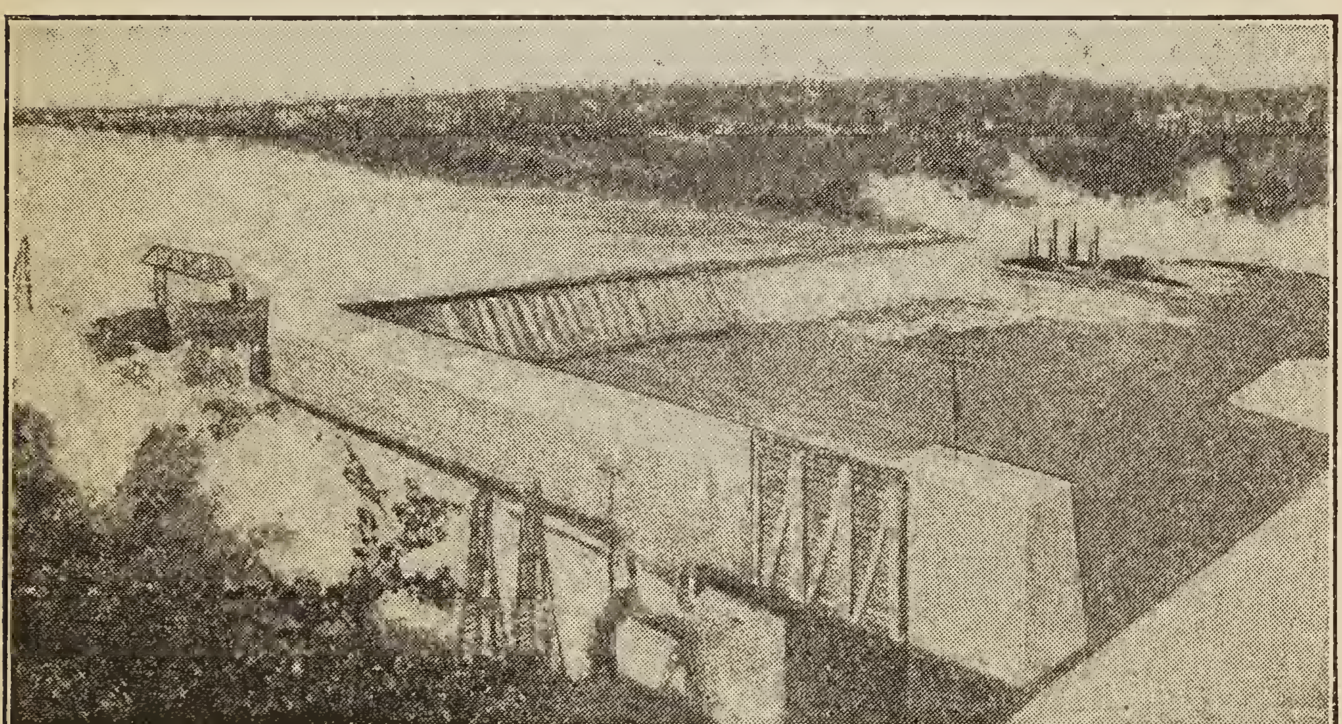


Fig. 79.—A Single Lock.

Courtesy of "The Scientific American"

An ordinary canal lock, Fig. 79, is used to raise or lower steamers a few feet to enable them to pass up or down stream, around a rapid, dam or waterfall. It is simply a short canal with a pair of gates at each end.

If the steamer is going up stream, it sails through the lower gates of the lock; the lower gates are closed behind it; water is admitted to the lock until its level is equal to that of the water above the lock; the upper gates are then opened, and the steamer sails out of the lock at the upper level. If the steamer is going down stream the reverse operation takes place.

If the difference in level is considerable but over some distance, a number of these locks are used, for example, if the difference in level were 80 feet in a distance of two miles. there might be, in the two miles, 4 locks with a difference of level of 20 feet each or 8 locks with a difference of 10 feet each, and so on.

When the difference in level is great in a short distance, however, a lift lock must be used.

LIFT LOCKS

Lift locks are so called because the whole lock, with the water in it and the ship, is lifted vertically from the low level to the high, or is lowered vertically from the high level to the low. They are always in pairs and the weight of one balances the weight of the other.

The lift lock shown in Fig. 80, is one that it is proposed to build on a canal between Lake Erie and Lake Ontario. It will take ships 650 feet long and of 30 foot draft, and will lift or lower them through a vertical height of 208 feet. The inner side of one will be connected with the inner side of the other by 56 steel cables which pass over 56 sheaves of 20 foot diameter. The outer side of each will be connected with large concrete counterweights by means of steel cables passing over 56 sheaves on each side. The locks will be raised and lowered by means of electrical power applied to the rims of each sheave. The gates at the ends of each lock and at the ends of the upper and lower canal will be opened and closed by being moved down and up vertically. The diagram shows how the locks will look when one ship is being raised and another lowered. The building at the right is a plant in which electrical power will be developed from the excess water from the upper canal. A small part only of this power will be used to operate the locks.

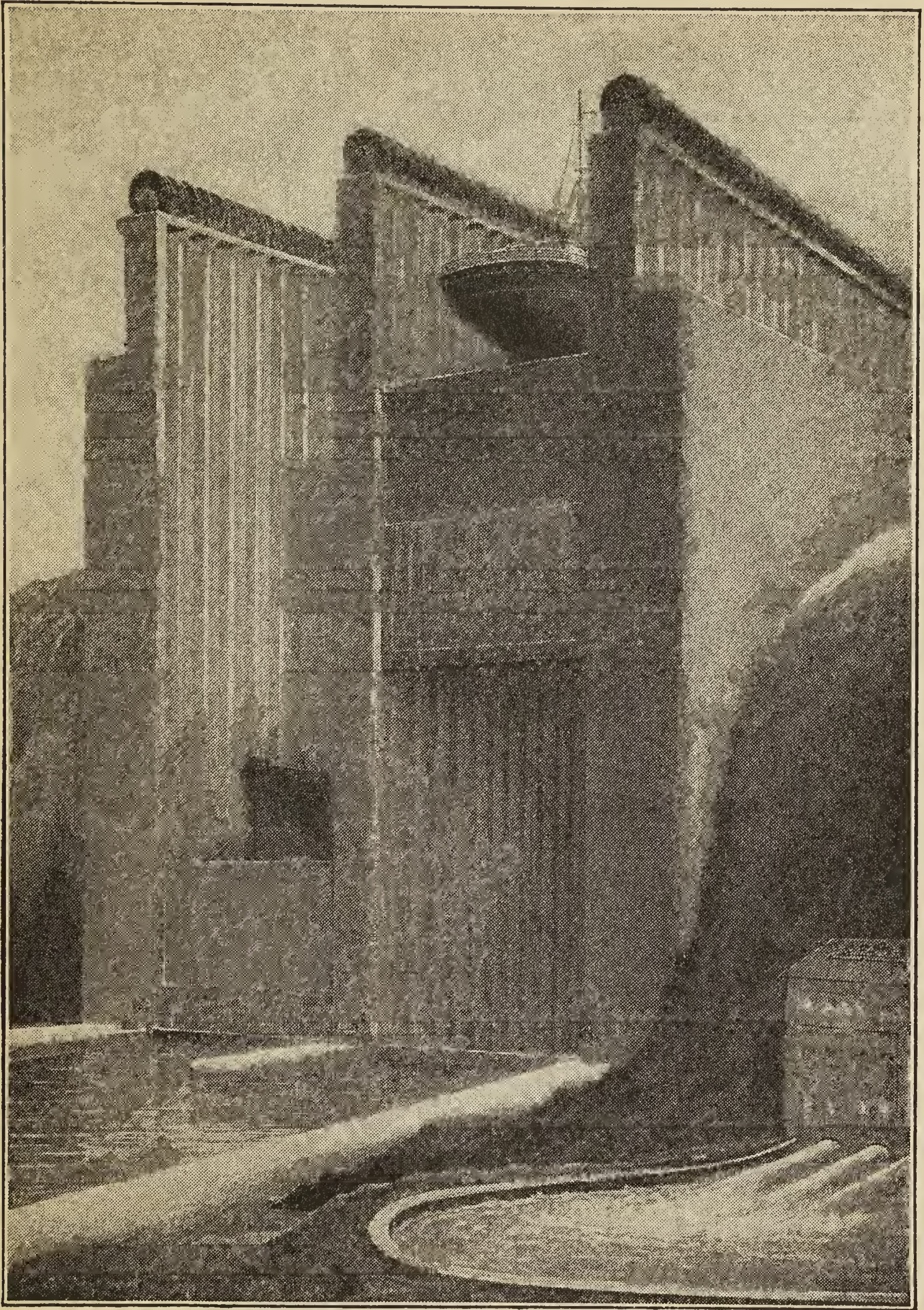


Fig. 80.—A Proposed Lift-Lock. *Courtesy of "The Scientific American"*

HYDRAULIC LIFT LOCKS

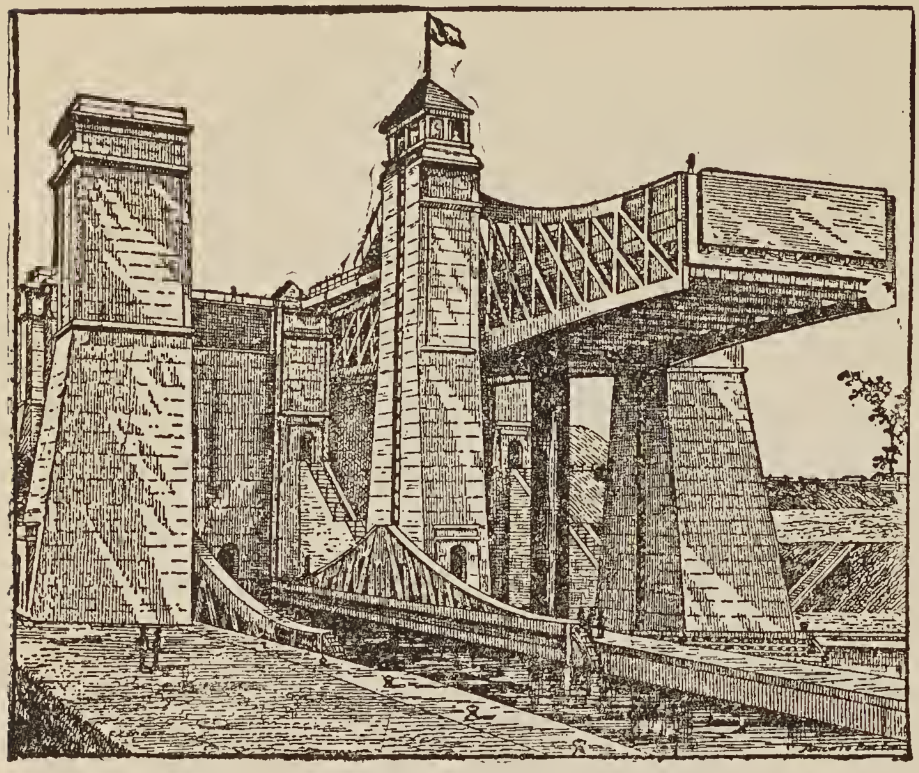


Fig. 81.—The Hydraulic Lift-Lock. *From the "Ontario High School Physics." By permission of the Pubishers.*

Hydraulic lift locks are so called because they are operated by means of water. Each lock is a large steel tank securely attached to the top of a very large ram which moves up and down in a deep cylinder. The two cylinders are connected by a pipe through which the water flows from one to the other, the flow being controlled, or stopped entirely, by means of a valve.

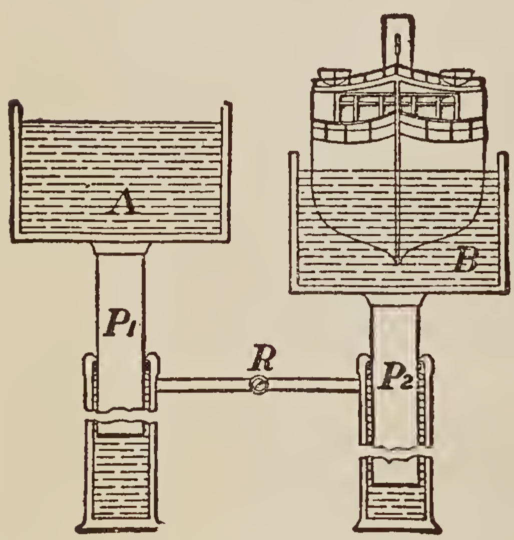


Fig. 82.—Showing How Lift-Locks Operate.

From the "Ontario High School Physics." By Permission of the Publishers

The operation of the locks will be understood from Fig. 82. If the steamer is going up stream: it sails into the lock B which is down and the lock gate is closed; a little water is admitted to the lock A which is up, to make it weigh more than the lower lock B and the steamer; the valve R is opened; the upper lock descends and its ram P_1 forces water from its cylinder into that of the lower lock; the pressure of this water raises the ram P_2, the lower lock and the steamer, to the upper level; the gates are opened; and the steamer sails out at the upper level.

If the steamer is going down stream; it sails into the upper lock and the gates are closed; water is admitted to the upper lock to make it weigh more than the lower lock; the valve R is opened; water is forced from the cylinder of the upper lock to that of the lower as the upper lock descends and the lower lock rises; the gates are opened; and the steamer sails out at the lower level.

Note. You might think that the presence of the steamer in one lock would make it weigh more than the other lock, but you will learn in Experiment 36 that a ship displaces its own weight of water and that therefore the one lock, plus water, plus steamer, weighs the same as the other lock plus water.

EXPERIMENT No. 30

To make and operate a hydraulic lift lock.

Use the apparatus shown in Fig. 83. The wide tubes and plungers represent the cylinders and rams of a real lift lock, and the clip represents the control valve. The inverted tumblers represent the locks, they should of course be right side up but you have no way of fastening them.

Place a button or pebble on the lower lock to represent a ship, open the clip and press down on the upper lock. Is the ship raised?

Lower a steamer in the same way.

Now place a steamer in the lower lock and press down on the upper lock while you open and close the clip from time to time. Do you find that the plungers stop as soon as you close the clip?

This shows how the rams of a real lift lock can be stopped anywhere by closing the valve R, Fig. 82. Water is incompressible, as you know from Experiment, No. 7, and when valve R is closed the rams cannot move because the water in the cylinders cannot be compressed and cannot move.

Repeat this but close the clip only partly.

Do you find that the plungers can move slowly and that you can regulate the speed by opening the clip more or less?

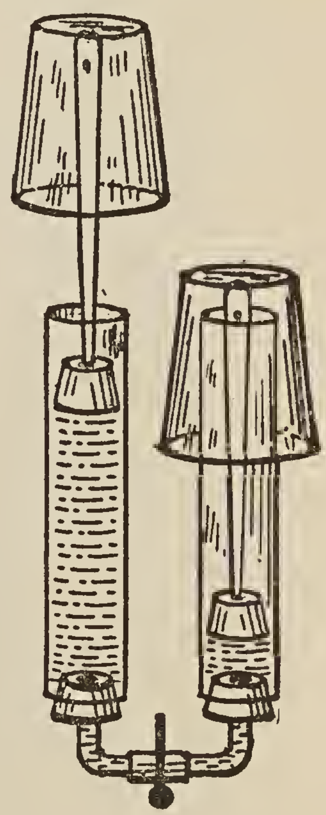


Fig. 83.—Illustrating the Working of the Hydraulic Lift-Lock.

This shows how the rams in a real lift lock can be allowed to move rapidly or slowly by opening the valve R more or less

In this experiment you have illustrated the working of a hydraulic lift lock: you have shown that the downward movement of one ram drives water into the second cylinder and that the pressure of this water raises the ram in the second cylinder; you have shown also that the rams can be stopped anywhere by closing the valve R or that they can be made to move very slowly by closing the valve partly.

THE PRESSURE EXERTED BY WATER

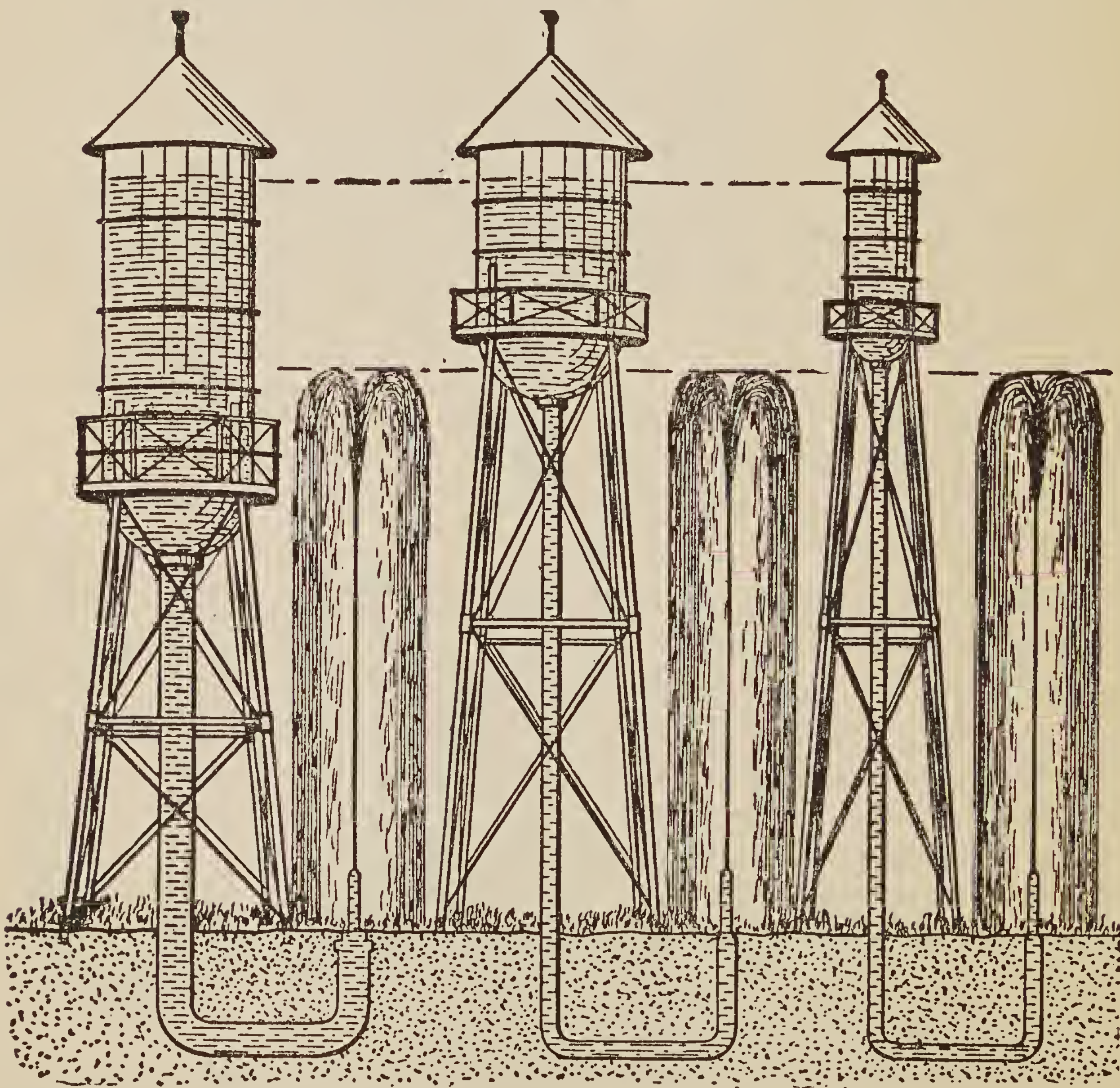


Fig. 84.—The Height of the Stream is Independent of the Size or Shape of the Tank and Pipe.

A very astonishing fact is illustrated in Fig. 84, namely that the pressure at the nozzles is the same no matter what size and shape the tank may be and no matter what size and shape the pipe may be, provided the water level in the tank is at the same distance above the nozzle in all cases. You will now prove this.

EXPERIMENT No. 31

To show that the pressure at a nozzle is independent of the size and shape of the tank and pipe.

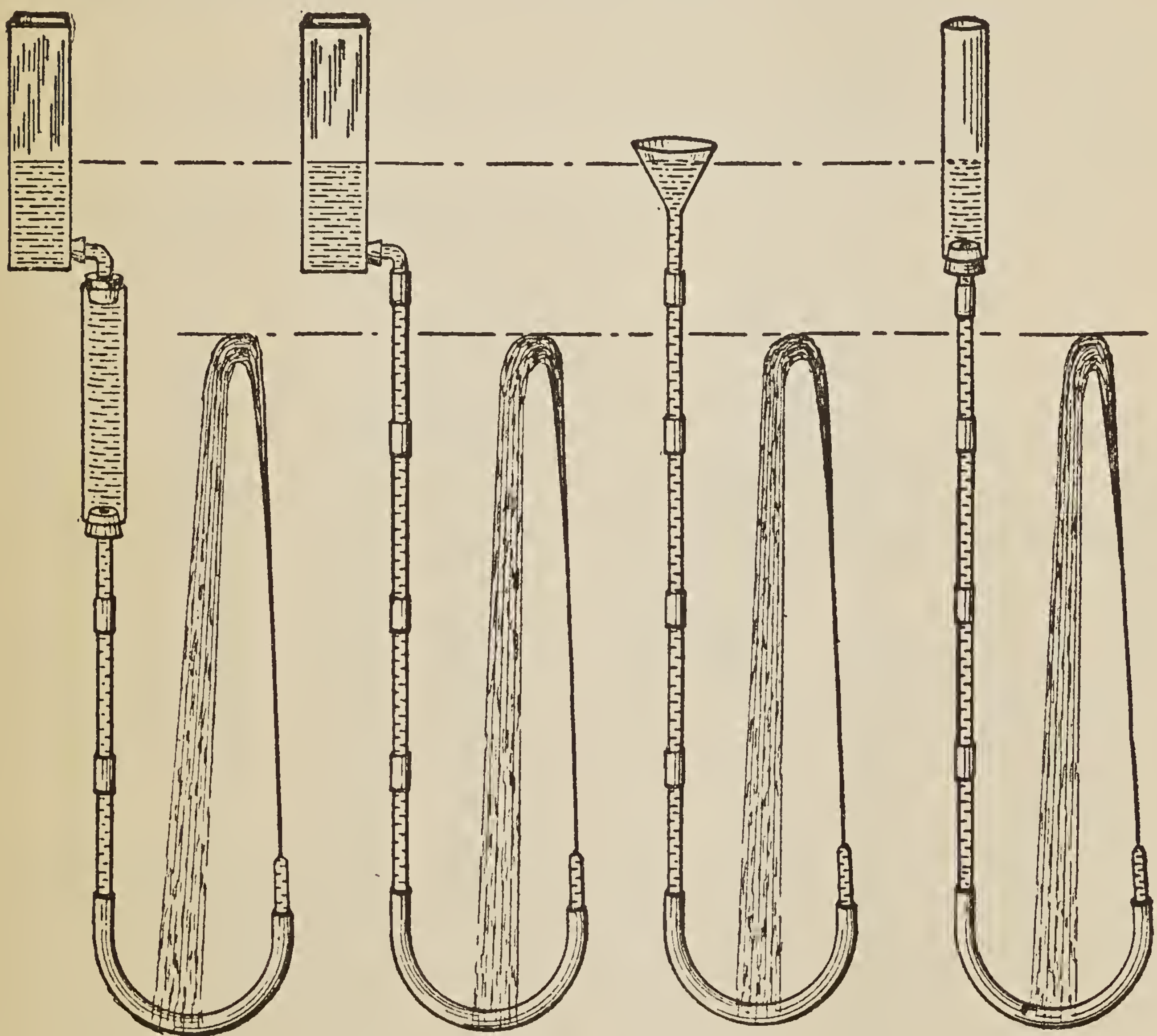


Fig. 85.—Showing That the Pressure at a Nozzle is Independent of the Size or Shape of the Tank or Pipe.

Make the experiments illustrated in Fig. 85 one after the other using the same nozzle in all. Are the streams of the same height in all cases if the water level in the tank is at the same distance above the nozzle?

You have shown here that the pressure exerted by water is independent of the **volume** of the water but that it depends upon the **height** of the water above the nozzle. This is known as the Hydrostatic Paradox which you will now illustrate.

THE HYDROSTATIC PARADOX

The Hydrostatic Paradox is stated as follows: The pressure exerted by a liquid on any base is **independent of the volume of the liquid,** but **depends only on the area of the base, the depth of the liquid, and the density of the liquid.**

Note. The **density** of a liquid is its weight per cubic foot, or per cubic inch, or per cubic centimeter.

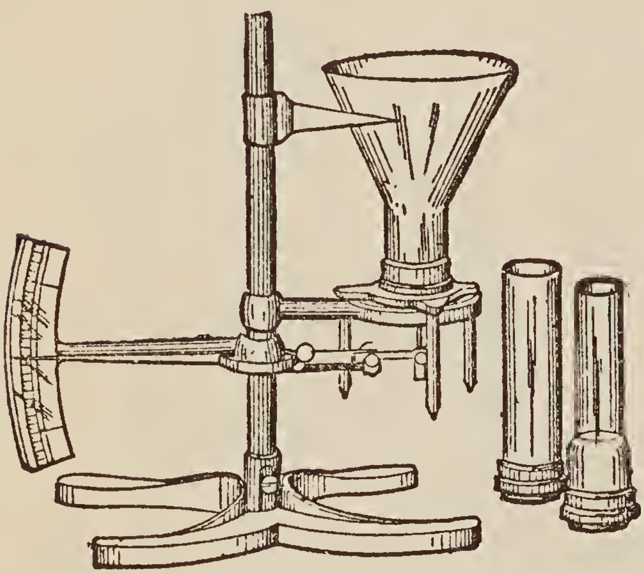


Fig. 86.—Illustrating the Hydrostatic Paradox.
Courtesy of The MacMillan Co.

The hydrostatic paradox is illustrated by means of the apparatus shown in Fig. 86. The three tops are of different sizes and shapes, but they fit a common base. The bottom of this base is covered by a sheet of rubber or by a sheet of corrugated metal. The base sinks as the pressure increases and moves the pointer, which indicates the pressure.

If the tops are screwed to the base, one after the other, and then filled with water to the same **height**, the pointer indicates the **same pressure** in all cases.

The volume of water in the tops is different in each case, but the pressure is the same in all. This shows that the pressure exerted by a liquid is **independent of the volume** of the liquid, provided the **area of the base,** the **depth** and the **density of the liquid** are the same in all cases.

Another form of this apparatus is shown in Fig. 87; the three tops fit the same base, but the bottom is a brass plate AB which is held on by a cord attached to one arm of a balance (not shown). The plate AB falls in each case when the water reaches the same height.

The hydrostatic paradox is also illustrated in 4; the three tubes are of very different volumes but the water stands at the same height in all.

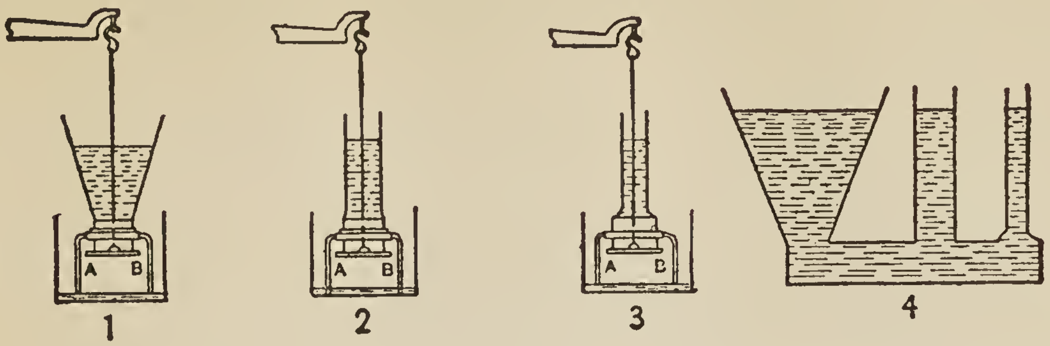


Fig. 87.—A Second Method of Illustrating the Hydrostatic Paradox
Courtesy of The MacMillan Co.

These experiments show that the pressure a liquid exerts on a given base is independent of the volume of the liquid, provided the area of the base, depth of the liquid, and density of the liquid are constant.

EXPERIMENT No. 32

To illustrate the hydrostatic paradox.

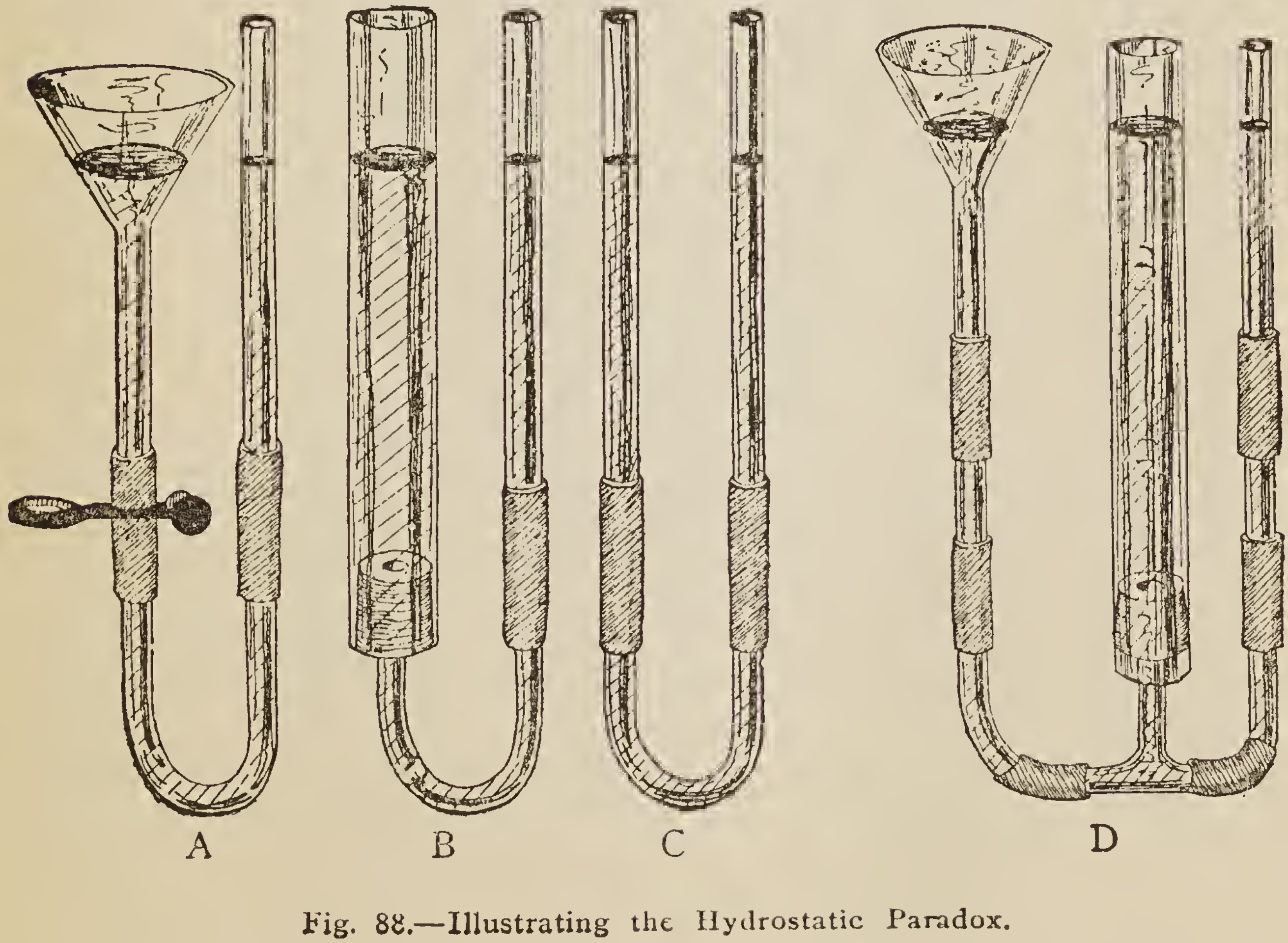


Fig. 88.—Illustrating the Hydrostatic Paradox.

Make the experiments A, B and C, Fig. 88, one after the other. Is the water in the small tube always at the same height as that in the funnel or large tube?

Arrange the apparatus as in D, Fig. 88. Is the water at the same level in all cases?

The funnel and wide tube, each contain more water than the small tube; nevertheless, the downward pressure of the water in each is balanced by the downward pressure of the water in the small tube.

You have shown here that the pressure exerted by a liquid is independent of the volume of the liquid, that is, you have illustrated the hydrostatic paradox.

EXPLANATION OF THE HYDROSTATIC PARADOX

The hydrostatic paradox seems impossible, and that is why it is called a paradox. It would seem to be self evident that the greater the volume of water above a base, the greater would be the pressure;

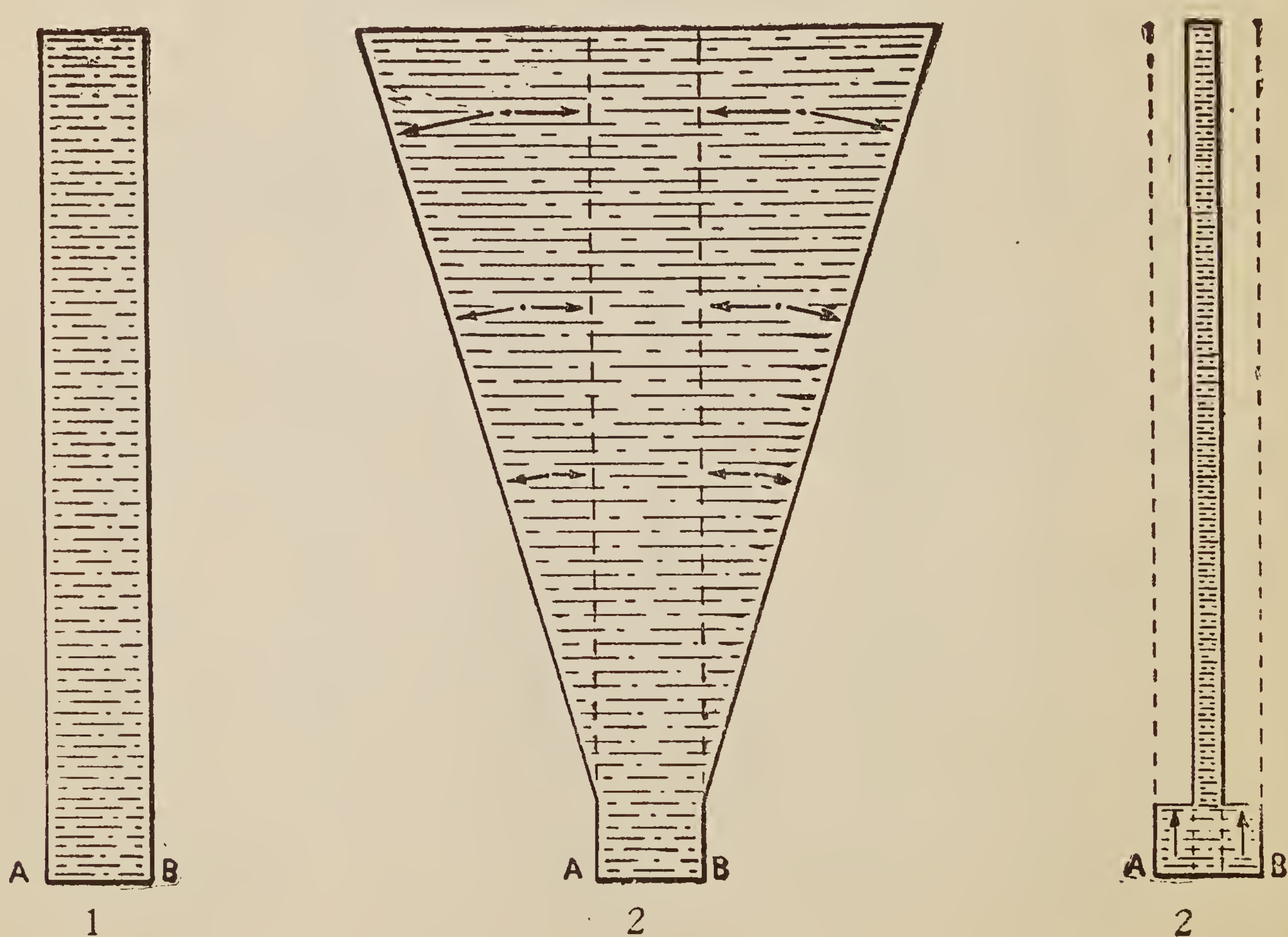


Fig. 89.—Explanation of the Hydrostatic Paradox.

and the less the volume, the less the pressure. You have shown above, however, that the pressure on a given base is independent of the volume of water and that it depends only on the depth.

The paradox is explained as follows:

In 1, Fig. 89, the base AB is subject to the pressure of the water in the cylinder above it, and in this case, the pressure is equal to the weight of the water.

In 2, Fig. 89, the same base AB has a much larger volume of water above it but the pressure is the same as in 1. You will understand why, if you consider the water outside the dotted lines. This water exerts a force perpendicular to the sides of the cone, and another force horizontally against the water between the dotted lines, see the arrows. Neither of these forces has any effect downward on the base and therefore the base is subject only to the weight of the water between the dotted lines. This weight is the same as in 1 and therefore the pressure on AB is the same as in 1.

In 3, Fig. 89, the base AB has a much smaller volume above it than in either 1 or 2, but still the pressure is the same as in 1 and 2. You will understand why from your knowledge of Pascal's law. The water above AB is exerting pressure downward, and according to Pascal's law this pressure is transmitted equally and undiminished in all directions. The pressure per square inch downward on the whole of AB, therefore, is equal to what it would be if the whole space between the outer dotted lines were filled with water. This pressure is equal to that in (1) and this is why the pressure in (3) is equal to that in (1).

HOW TO CALCULATE THE PRESSURE EXERTED BY WATER

The density (weight) of fresh water is 62½ lbs. per cubic foot and if in (1) Fig. 89, the base AB is 1 square foot and the height of the water is 10 feet, there are 10 cubic feet of water in the tank and the total pressure on the bottom is 10 x 62.5 = 625 lbs.

Since the pressure exerted by water is independent of the volume of the water and depends only on the area of the base, the height, and the density of the water, the pressure on AB in (2) and (3) is 625 lbs., the same as in (1).

The rule for calculating the pressure in any case is: Pressure on any base = area of base in square feet x height of water in feet x density of water (weight of 1 cubic foot) or, Pressure = area x height x density.

In the example given:

Pressure $= 1 \times 10 \times 62.5 = 625$ ℔s. per square foot.

To find the pressure per square inch, first find the pressure per square foot and then divide the result by 144, the number of square inches in 1 square foot. For example, the pressure on 1 square inch of AB in any of the tanks illustrated is $625 \div 144 = 4.34$ ℔s.

PRESSURE UNDER WATER
THE DEPTH BOMB — TORPEDO — SUBMARINE

THE DEPTH BOMB

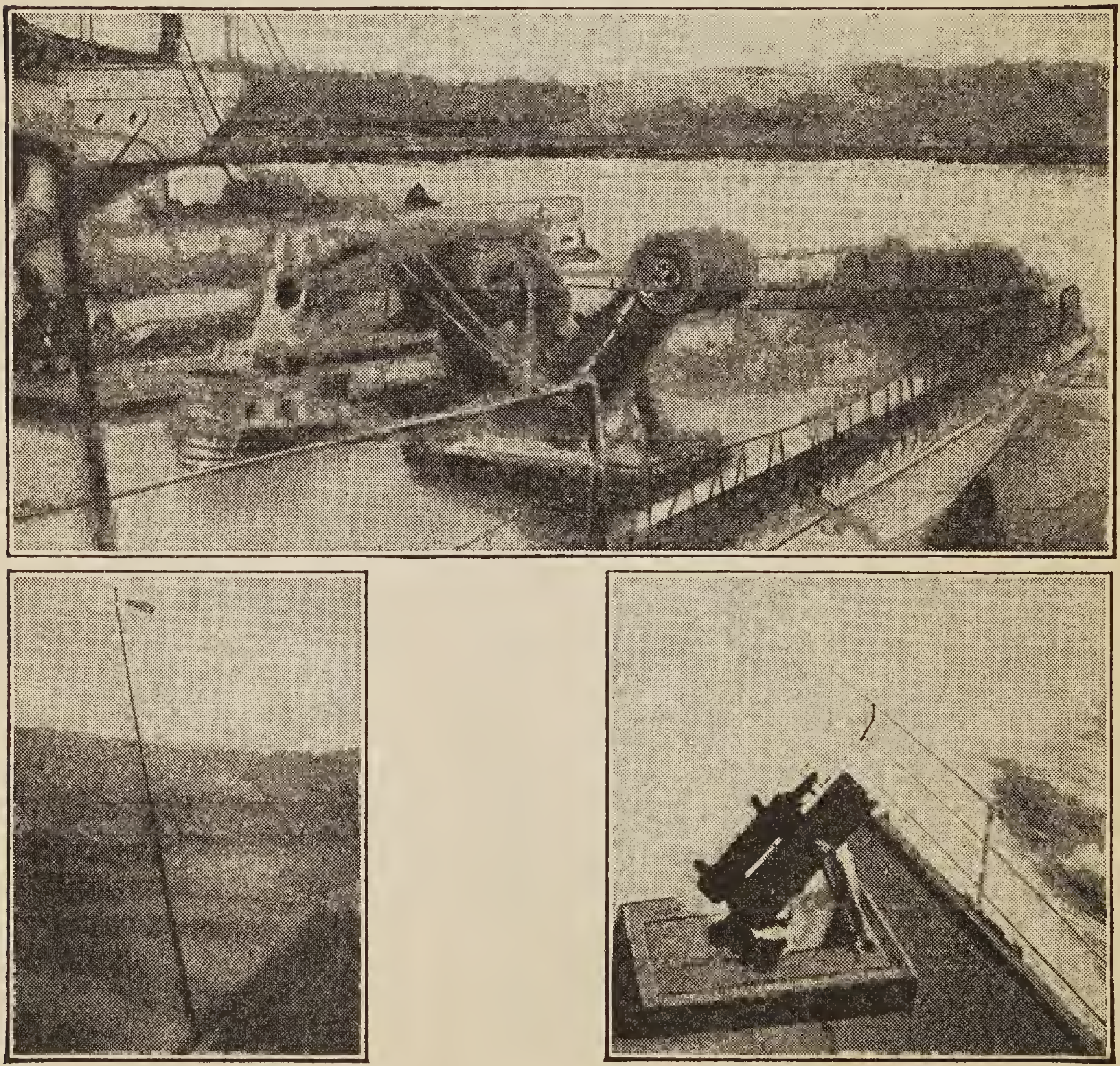


Fig. 90.—The Depth Bomb. *Courtesy of "The Scientific American"*

The depth bomb is used by submarine chasers to destroy submarines. It is a steel cylinder filled with high explosives and equipped with a trigger which sets off the explosive at any desired depth under water.

The trigger is released by means of a small plunger which is exposed to the pressure of the sea water on the outside and is supported by a spring on the inside. The pressure of the water increases as the bomb sinks and forces the plunger in farther against the spring, but the spring can be so adjusted that at any desired depth the plunger releases the trigger and the bomb explodes.

When the chaser sights a submarine it steams for it and if it is still above water, attacks it with guns; but if it has submerged, the chaser steams in circles around the spot where it disappeared and drops or fires bombs adjusted to explode at different depths.

THE TORPEDO

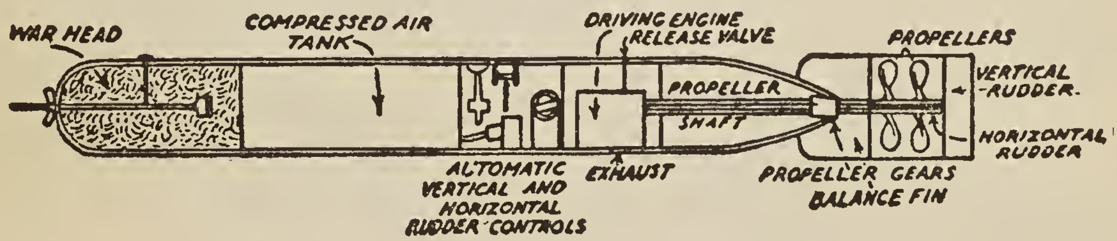


Fig. 91.—The Principle Parts of the Torpedo.
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Copyright by Frederick A. Stokes Co.

The torpedo is a cigar shaped tube loaded in the head with high explosives which are set off by a contact pin. It is driven by means of a compressed air motor and is steered by horizontal and vertical rudders.

We are interested in the horizontal rudder particularly at this point. It steers the torpedo to a depth of 20 feet under water and keeps it at this depth. It does this by means of the pressure of the sea water. The horizontal rudder is controlled by a piston, Fig. 92, which is exposed to the pressure of the sea water on the

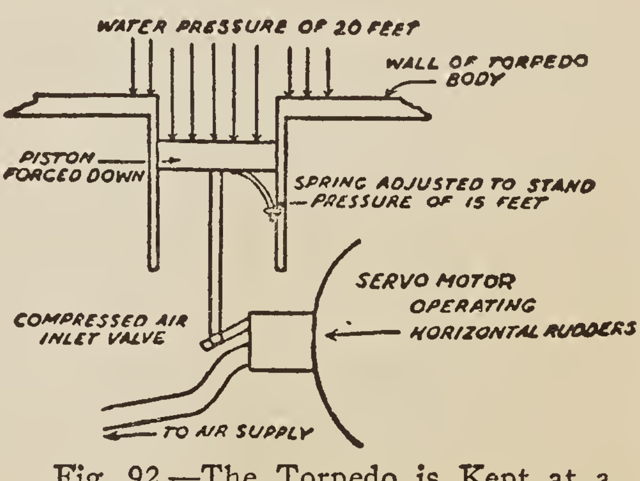

Fig. 92.—The Torpedo is Kept at a Depth of 20 feet by Water Pressure.
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outside and is supported by a spring on the inside. This piston and its spring are so adjusted that at 20 feet under water the rudder is exactly horizontal, but at a greater or less depth the rudder is so turned as to bring the torpedo back to a depth of 20 feet.

THE SUBMARINE

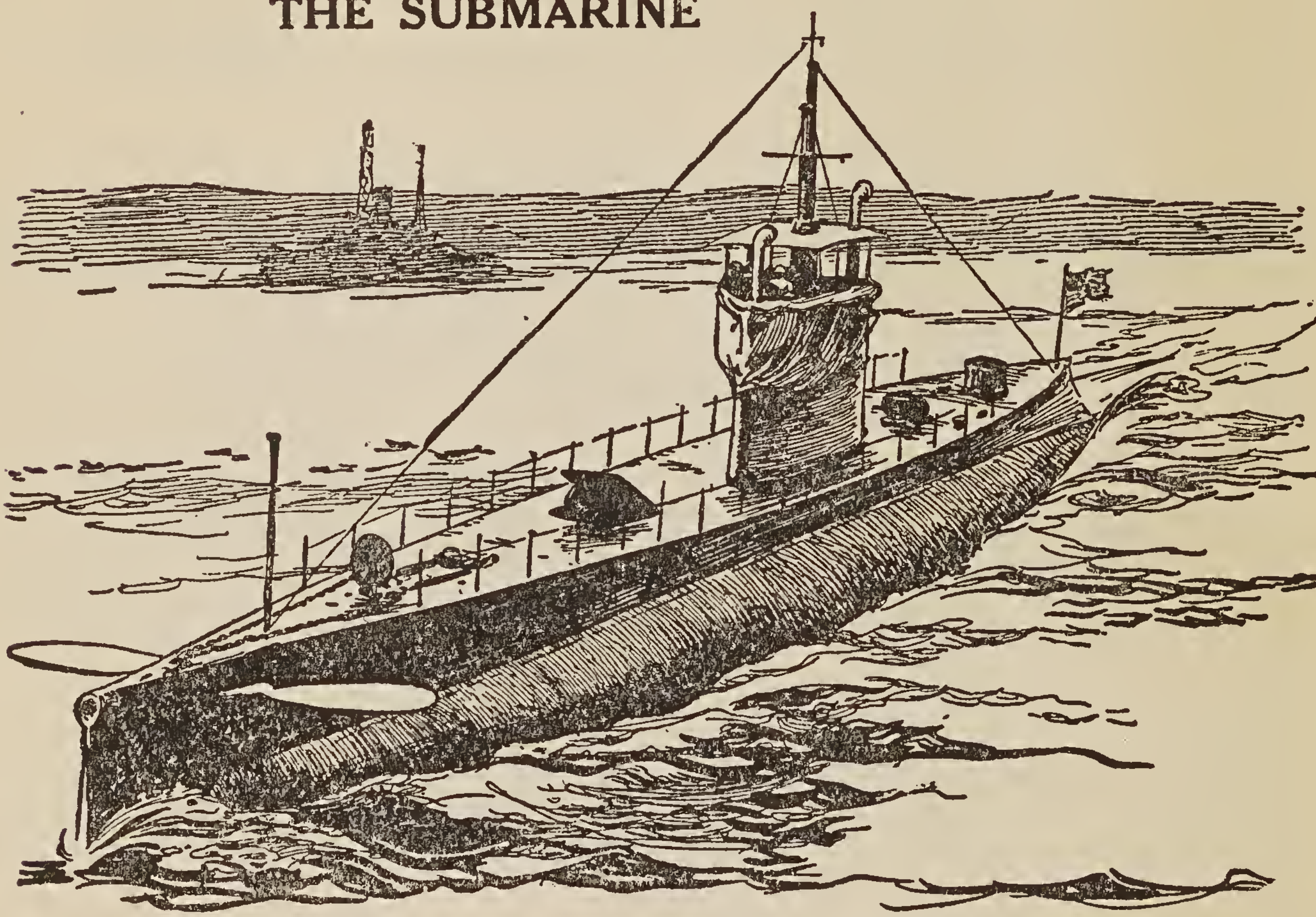
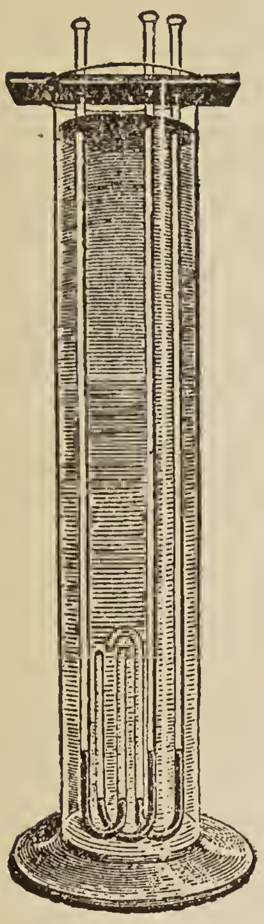


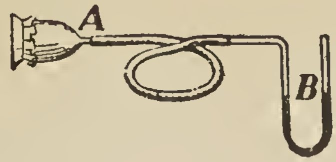
Fig. 93.—The Submarine.
Reproduced by Permission from the "Boy's Book of Submarines" by Frederick Collins. Copyright by Frederick A. Stokes Co.

The submarine must be able to stand enormous pressures when under water and for this reason it is made in the shape of a cylinder with pointed ends, because this curved shape enables it to stand greater pressure than it could if its sides were flat; also it is made of steel because this is the strongest material available.

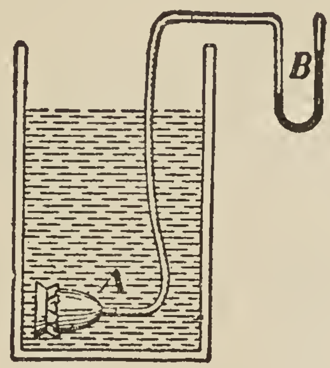
You cannot experiment with the depth bomb, torpedo, and submarine, of course, but you can make experiments to illustrate the water pressure under which they operate. You can show that the pressure under water increases with the depth, that it is equal in all directions at any depth, etc., and this you will now do.



A



B



C

Fig. 94.—Showing That the Pressure at a Given Depth in a Liquid is Equal in All Directions.

A—Courtesy of The MacMillan Co. B and C—From the "Ontario High School Physics." By permission of the Publishers

EXPERIMENT No. 33

To show that the pressure under water increases with the depth and that it is equal in all directions at any given depth.

This is usually shown by means of the apparatus A, Fig. 94. The U shaped bend of the three tubes contain mercury to the same depth. Both ends of the tubes are open. The short ends point upward, sidewise and downward respectively. When the short ends of these tubes are lowered in water, the mercury shows that the pressure increases with the depth, and that it is equal in all directions at any given depth.

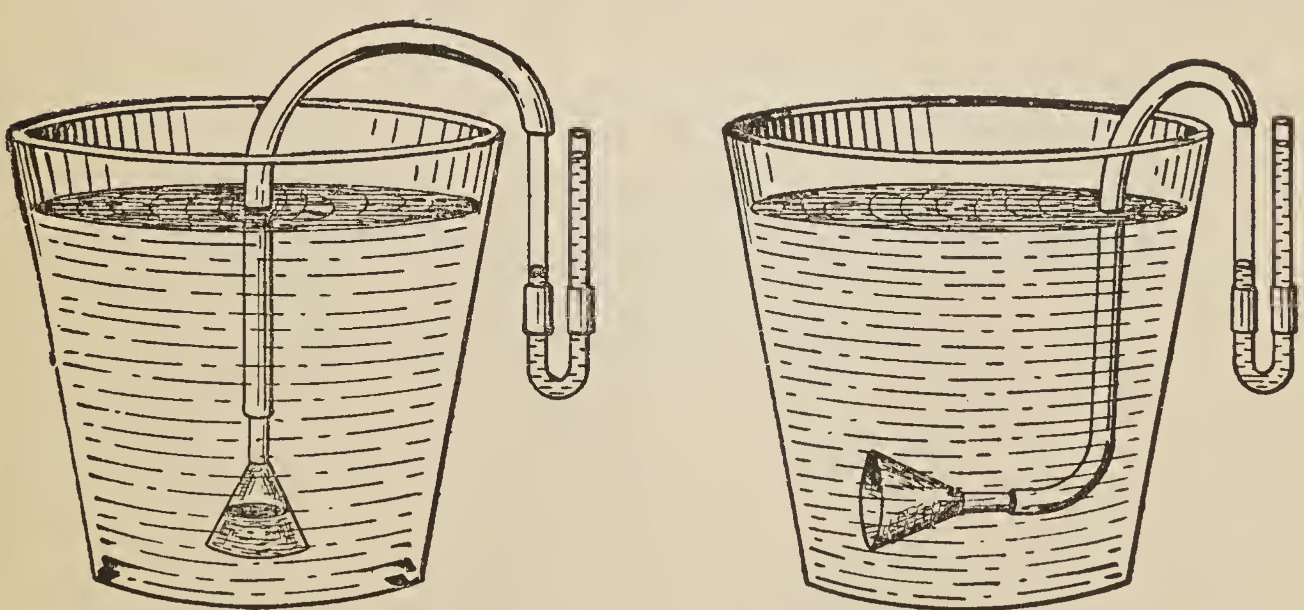


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Fig. 95.—The Pressure is Equal in All Directions at any Given Depth.

This fact is illustrated in another way by means of the apparatus, B and C, Fig. 94. A thistle tube covered by a sheet of rubber is placed under water and the water in the U tube indicates a greater pressure the greater the depth. If the thistle tube is turned in all directions at any given depth, the water in the U tube shows that the pressure is equal in all directions at this depth.

Illustrate these facts by means of the apparatus, Fig. 95.

Shove the funnel straight down (1). Does the pressure increase with the depth?

Turn the funnel sidewise (2) and upward at any depth. Is the pressure equal in all directions at any given depth?

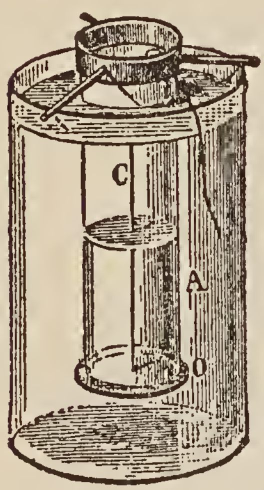


Fig. 96.—The Upward Pressure at any Point Under Water is Equal to the Downward Pressure at this Point.
Courtesy of The MacMillan Co.

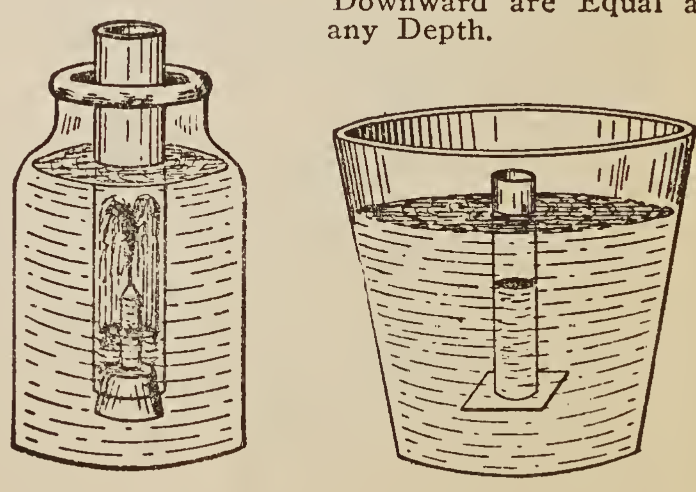
EXPERIMENT No. 34

To show that water exerts pressure upward on anything under its surface and that the upward pressure is equal to the downward pressure at any given depth.

This is usually shown with the apparatus Fig. 96. If a glass lamp chimney A, is fitted with a thin ground glass bottom O which is held over one end by a thread C, while this end is placed in water, it is found that the bottom remains on when the thread is released. This shows that water exerts pressure **upward** on anything under its surface.

If now water is poured into the chimney, the bottom

Fig. 97.—Showing That the Pressure Upward and Downward are Equal at any Depth.



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remains on until the level inside the chimney is the same as the level outside and this is true at any depth. This shows that the pressure upward at any depth under water is equal to the pressure downward of the column of water inside the chimney. In other words, it shows that the pressure upward at any depth under water is equal to the pressure downward at this depth.

Illustrate this with the apparatus (1) Fig. 97. Put the stoppered end in water. Is a fountain produced and does the flow stop when the level inside is equal to that outside the tube?

Use the apparatus (2) Fig. 97, hold the rubber sheet on until it is under water. Does it remain?

Pour water into the tube. Does the sheet fall off when the level inside is equal to that outside?

You have shown here that water exerts pressure upward against anything under its surface and that the upward pressure is equal to the downward pressure at any given depth.

HOW TO CALCULATE THE PRESSURE ON DEPTH BOMB, TORPEDO AND SUBMARINE

Sea water is heavier than fresh water; it weighs 64 ℔s. per cubic foot while fresh water weighs only 62½ ℔s. per cubic foot.

DEPTH BOMB

A depth bomb is set to explode at a depth of 250 feet. If sea water weighs 64 ℔s per cubic foot, what is the pressure per sq. in. against the plunger at this depth?

Note: Calculate the pressure per square foot and divide this by 144, the number of square inches in one square foot.

$$\text{Pressure} = \frac{\text{Area x depth x density.}}{144}$$

$$\text{Pressure} = \frac{1 \times 250 \times 64}{144} = 111.1 \text{ ℔. per sq. in.}$$

TORPEDO

A torpedo is set to travel at a depth of 15 feet under water. What is the pressure per sq. in. on the steering plunger at this depth?

$$\text{Pressure} = \frac{\text{Area x depth x density.}}{144}$$

$$\text{Pressure} = \frac{1 \times 15 \times 64}{144} = 6.6 \text{ ℔s. per sq. in.}$$

SUBMARINE

What is the pressure per square foot on the outside of a submarine at an average depth of 150 feet in water?

Pressure = Area x depth x density.
Pressure = 1 x 150 x 64 = 9600 ℔s. per sq. ft.

BUOYANCY

WHY DOES A STEEL SHIP FLOAT?

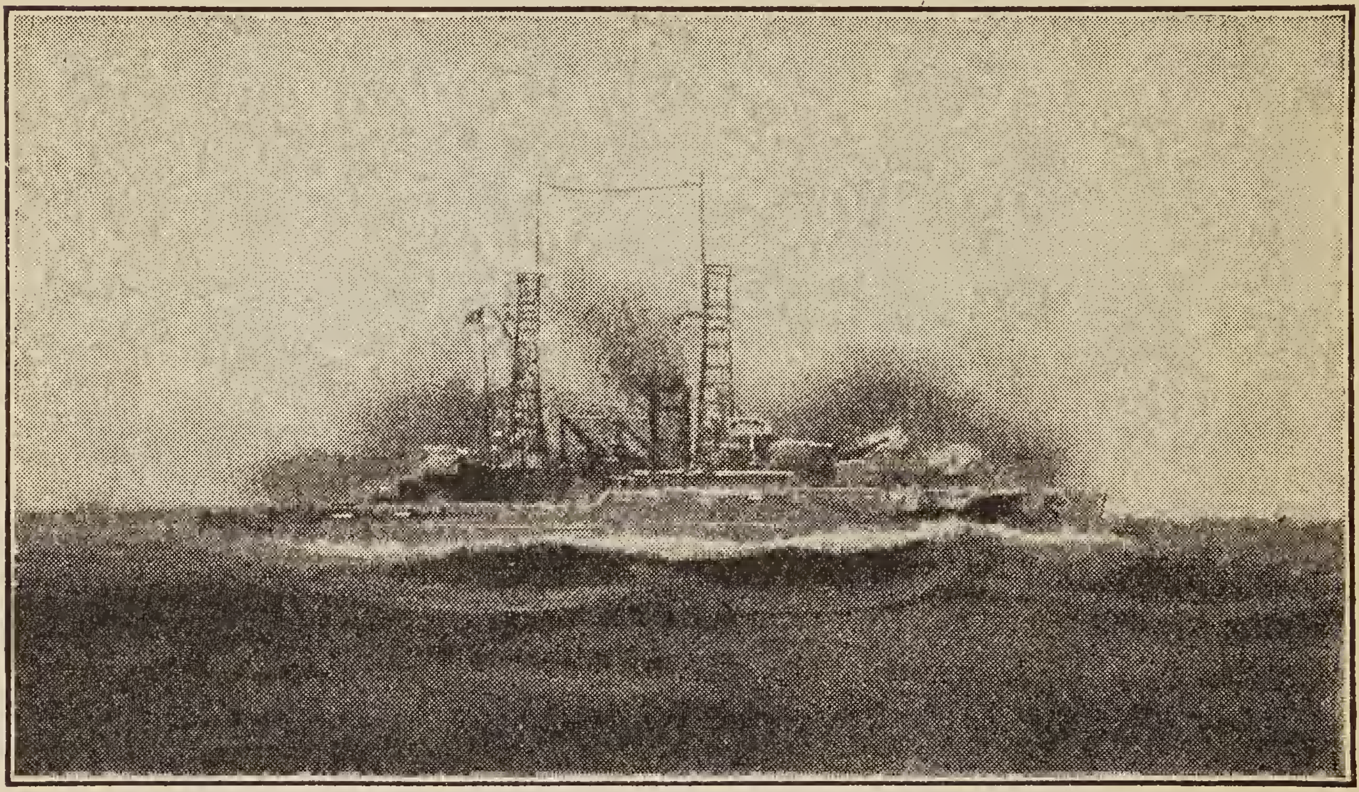


Fig. 98.—Why Does This Steel Ship Float?

Courtesy of "The Scientific American"

Modern ships are made of steel, example, the superdreadnaught shown in Fig. 98, and although steel is over seven times as heavy as water, bulk for bulk, steel ships float. Why is this?

You know the answer, at least partly. You know that if a ship were a solid lump of steel, it would sink. You know also that a ship is hollow, except for its equipment, and that this hollowness in some way enables it to float.

The true reason is that the ship as a whole is lighter than an equal volume of water.

You will show in the following experiments that water exerts a buoyant force on anything placed in it, and that as a result: things which are lighter than an equal volume of water float on water; while things which are heavier than an equal volume of water sink but are lighter under water than above water.

Fig. 99.—Illustrating the Buoyant Effect of Water.

EXPERIMENT No. 35

To illustrate the buoyant effect of water.

Find about your home an empty tin can with a tight lid. Submerge it partly as in (1) and release it. Does it shoot upward? This buoyant effect of the water is due to the upward pressure of the water.

Submerge it entirely as in (2) and (3) and release it. Does it shoot upward? This buoyant effect shows that the upward pressure of the water on the under side of the can is greater than its downward pressure on the top side.

Fill the can with water, submerge and release it. Does it sink? Lift the full can under water and out of water. Is it much lighter when under water? It is lighter because the water buoys up part of its weight.

THE LAW OF ARCHIMEDES

The exact law which applies to the buoyancy of liquids was discovered by a Greek philosopher Archimedes 200 years before the Christian era began. It is called the **law of Archimedes** and it is as follows: **the buoyant force exerted by a liquid on a body immersed in it, is exactly equal to the weight of the liquid displaced by the body.**

It is also stated more concisely as follows: a body when placed in a liquid appears to lose weight equal to the weight of liquid it displaces.

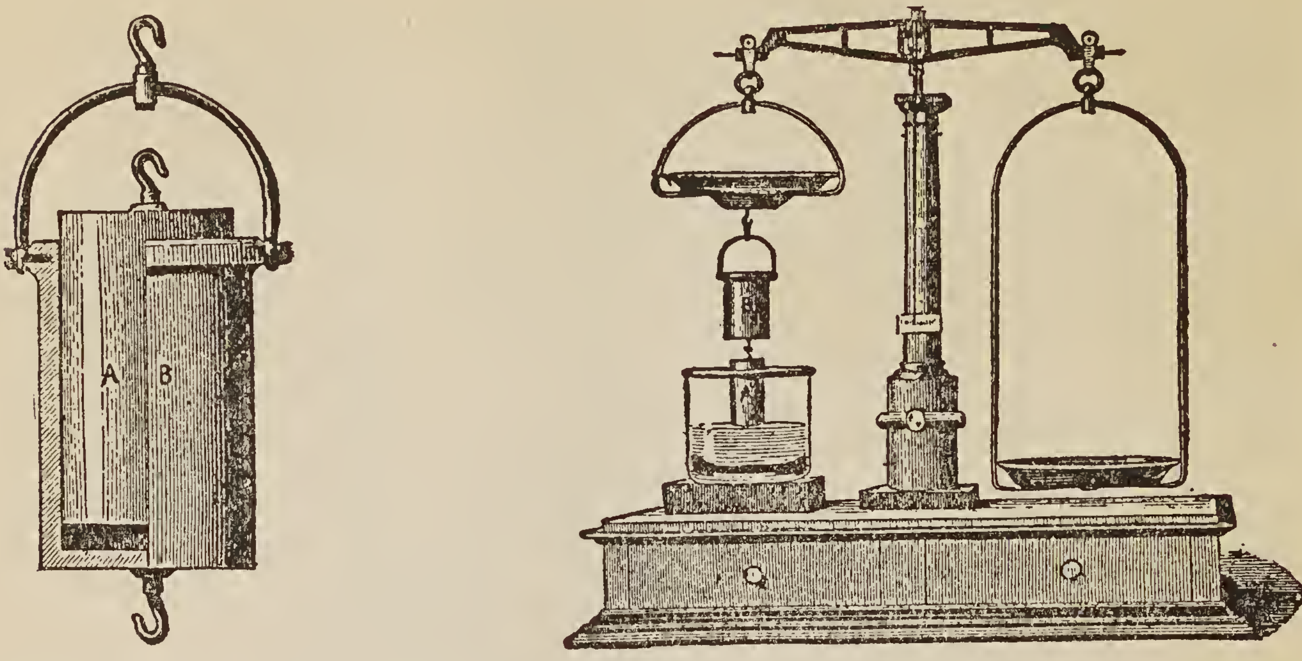


Fig. 100.—The Cup and Cylinder. One Method of Illustrating the Law of Archimedes.
Courtesy of The MacMillan Co.

The law of Archimedes is illustrated by means of the apparatus shown in Fig. 100. The solid cylinder A is so made that it just fits the cup B, that is, the cylinder has exactly the same volume as the cup.

The experiment is as follows: The cylinder A is attached to the bottom of the cup B and both are suspended from one pan of a balance. Weights are added to the other pan until the cup and cylinder are just balanced.

If then, a vessel of liquid is raised up under the cylinder A until it is completely submerged, the cup and cylinder appear to lose weight because the liquid buoys up the cylinder. If now the cup B is filled with the liquid, the balance is exactly restored.

Now the weight of the liquid which fills the cup is equal to that of the liquid displaced by the cylinder and therefore this experiment proves the law of Archimedes, namely, the buoyant force exerted by a liquid on a body immersed in it is equal to the weight of the liquid displaced by the body.

The law of Archimedes is also illustrated by means of the apparatus shown in Fig. 101 and by means of a spring balance, not shown.

The body is first weighed on the spring balance in air, then in the liquid, and the apparent loss in weight in the liquid is determined.

The vessel with the spout is then filled with the liquid until it overflows, the body is placed in the liquid, and the liquid displaced is weighed.

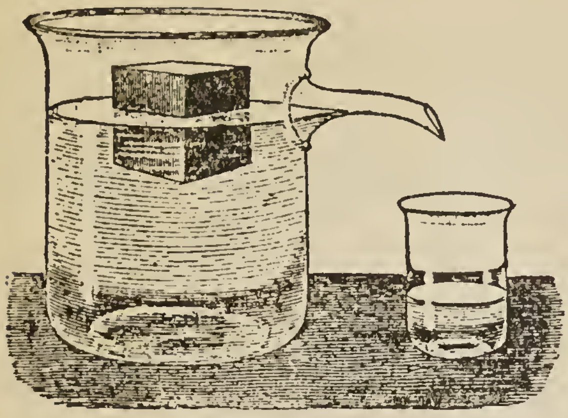


Fig. 101.—Another Method of Illustrating the Law of Archimedes. *Courtesy of The MacMillan Co.*

The apparent loss in weight of the body is then compared with the weight of liquid displaced by the body, and it is found that in every case they are equal.

You will now make experiments to illustrate the law of Archimedes for bodies which float on water and for bodies which sink in water, also you will illustrate some of the applications of this law.

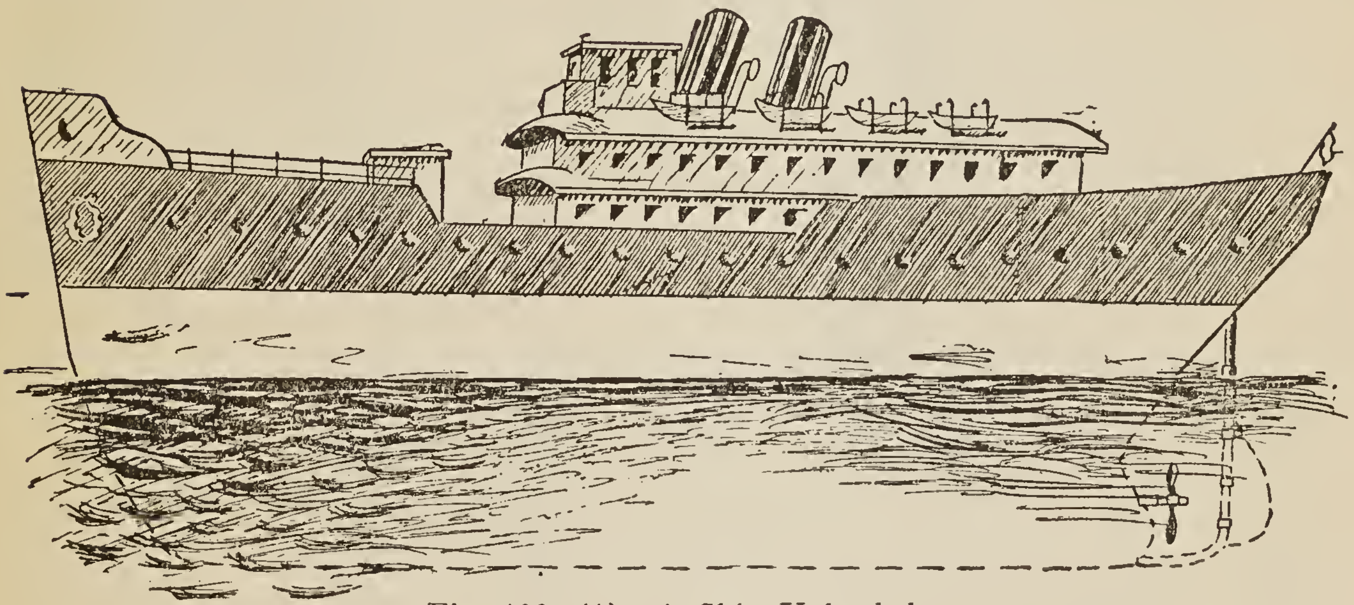


Fig. 102. (1)—A Ship Unloaded.

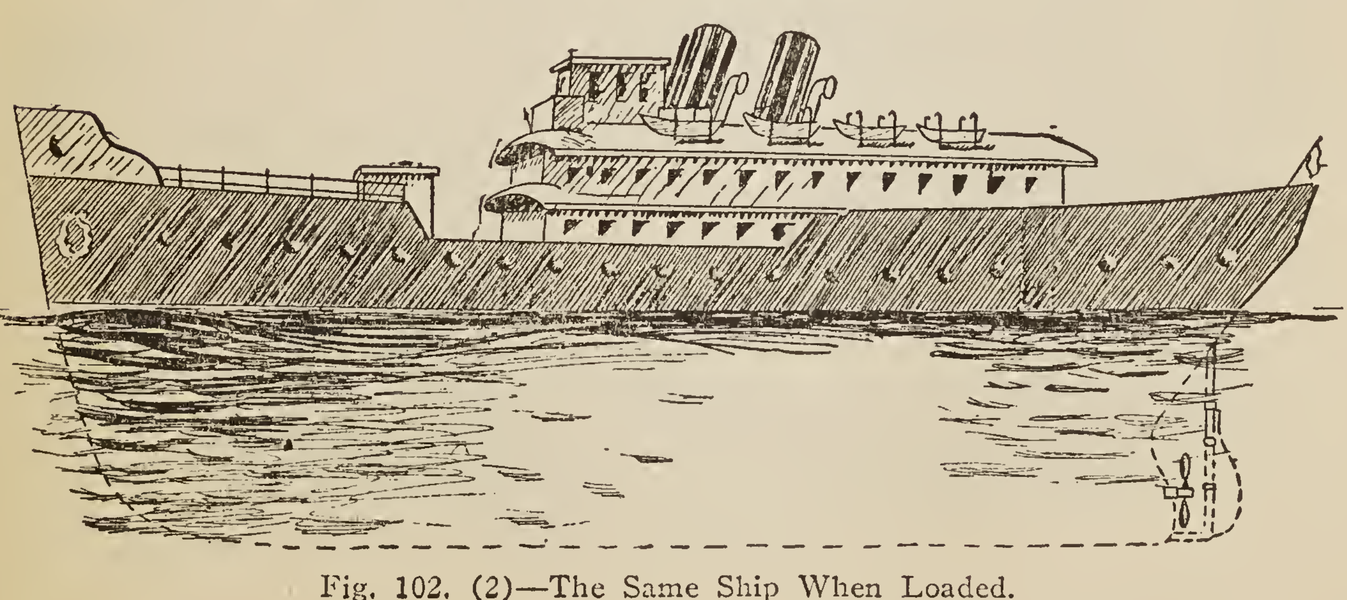


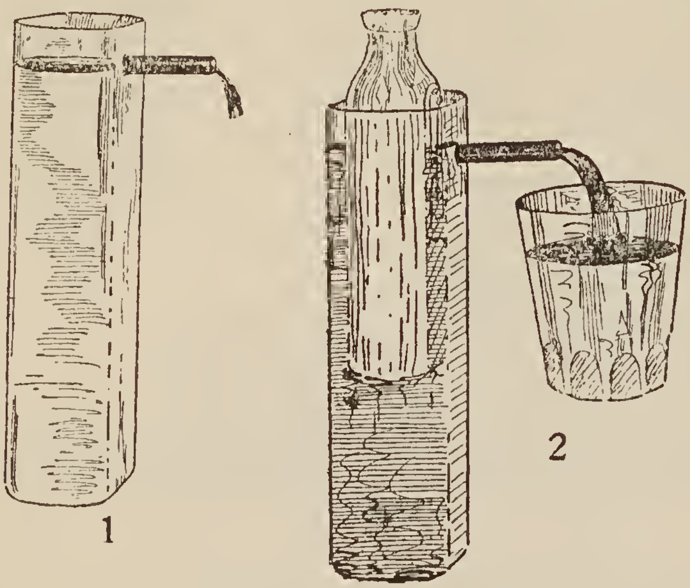
Fig. 102. (2)—The Same Ship When Loaded.

A ship is a floating body and it displaces its own weight of water. If, for example, a ship weighs 10,000 tons it displaces 10,000 tons of water. If 5000 tons of cargo are added it floats deeper in the water and displaces 15,000 tons of water, and so on.

You will now show that a floating body displaces its own weight of water.

EXPERIMENT No. 36

To illustrate the law of Archimedes for bodies which float.



Use the empty glass bottle as the floating body. Close the lower hole in the metal tank with a No. 1 stopper, put the large coupling in the upper hole, fill the tank with water **until water runs out through the coupling and stops.** (1) Fig. 103. Now place the bottle slowly in the water and catch the water it displaces, (2) Fig. 103.

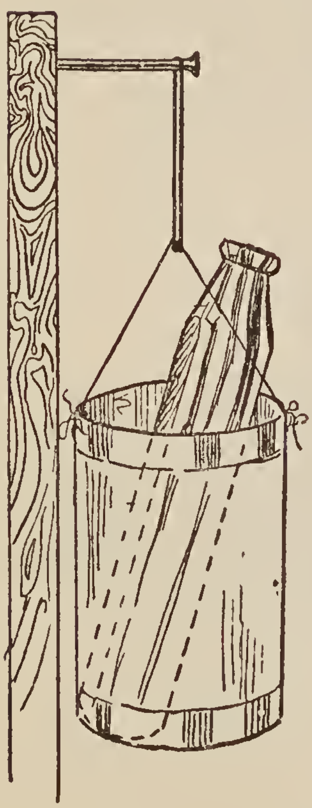


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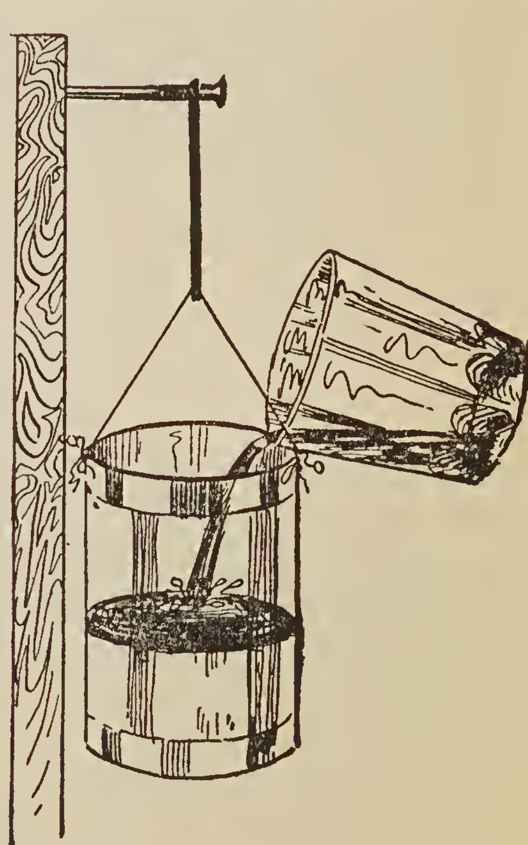
Fig. 103.—A Floating Body Displaces Its Own Weight of Water.



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Now make a spring balance with a bucket, (3), Fig. 103, as follows: Find a tin can around your home, punch two nail holes near the top, and attach the can to the elastic band by means of a cord, suspend the band from a nail driven in a piece of board.

Now put the bottle in the can and mark the position of the bottom of the elastic band. Then take the bottle out and pour into the can the water displaced by the bottle, (4), Fig. 103. Do you find that the displaced water weighs the same as the bottle, that is, that a floating body displaces its own weight of water?

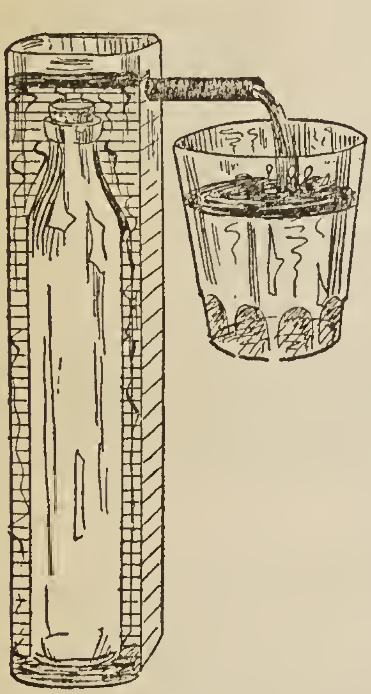


Fig. 104 - 1.—A Body Which Sinks Loses Weight Equal to the Weight of Water it Displaces.

You have here illustrated the law of Archimedes for floating bodies.

EXPERIMENT No. 37

To illustrate the law of Archimedes for bodies which sink in water.

Use the bottle filled with water to represent a body which sinks in water, fill the metal tank, Fig. 104, with water until it overflows through the coupling and stops. Place the bottle in the tank slowly and catch the water it displaces.

Now attach the full bottle to the bottom of the balance (2) and mark the position of the bottom of the rubber band. Submerge the bottle in water (3), mark the position of the bottom of the rubber band again, then pour the displaced water into the can, (4). Does the balance descend to the mark (2)? That is, is the buoyant effect on the bottle equal to the weight of the water displaced by the bottle?

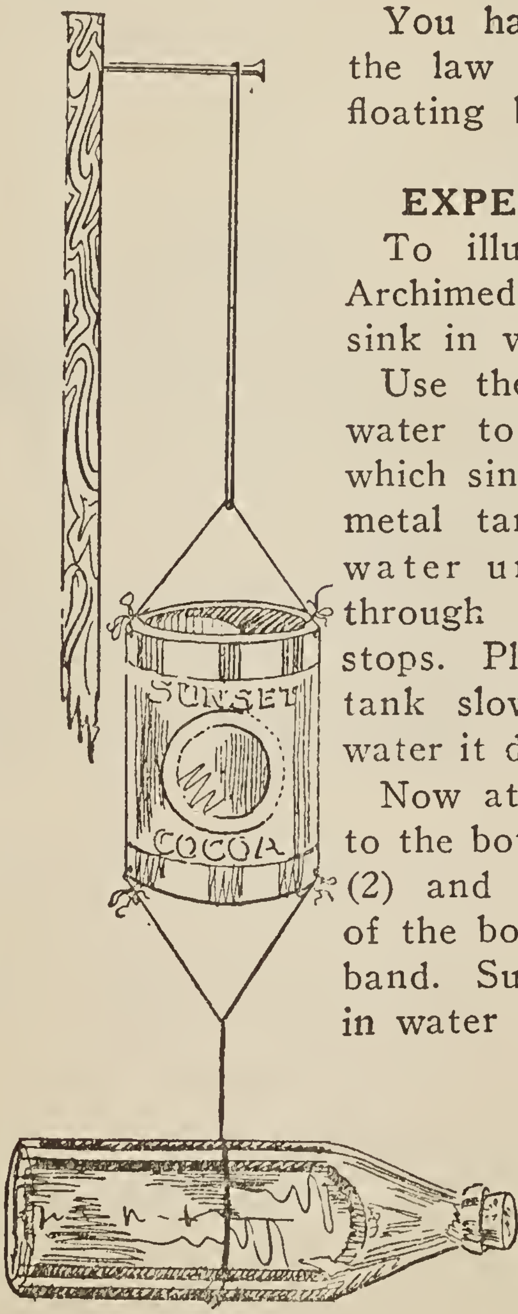


Fig. 104 - 2

You have here illustrated the law of Archimedes for bodies which sink in water.

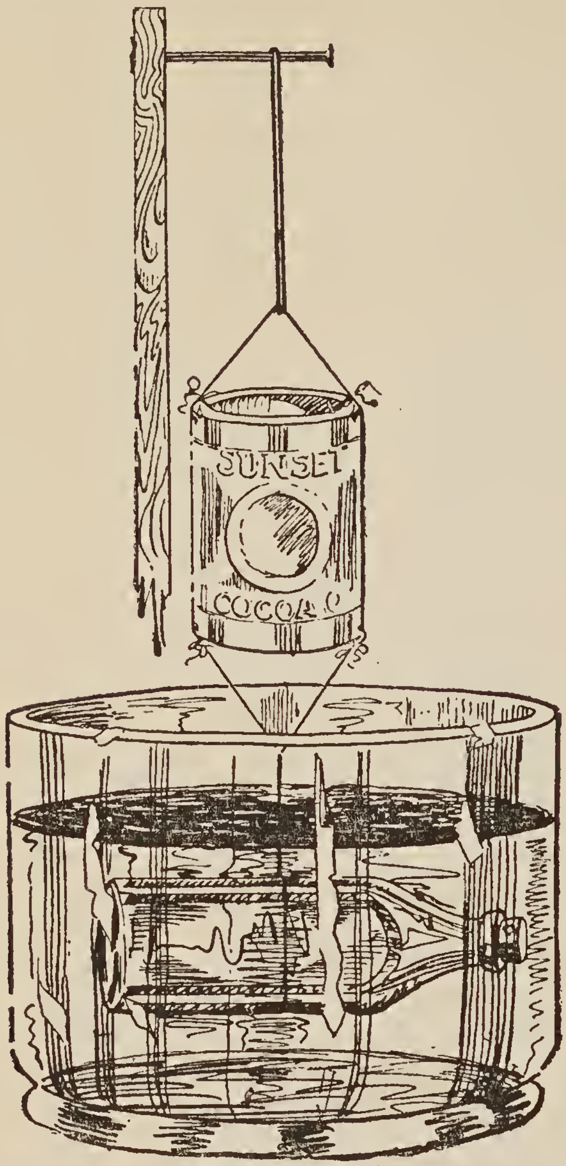


Fig. 104-3

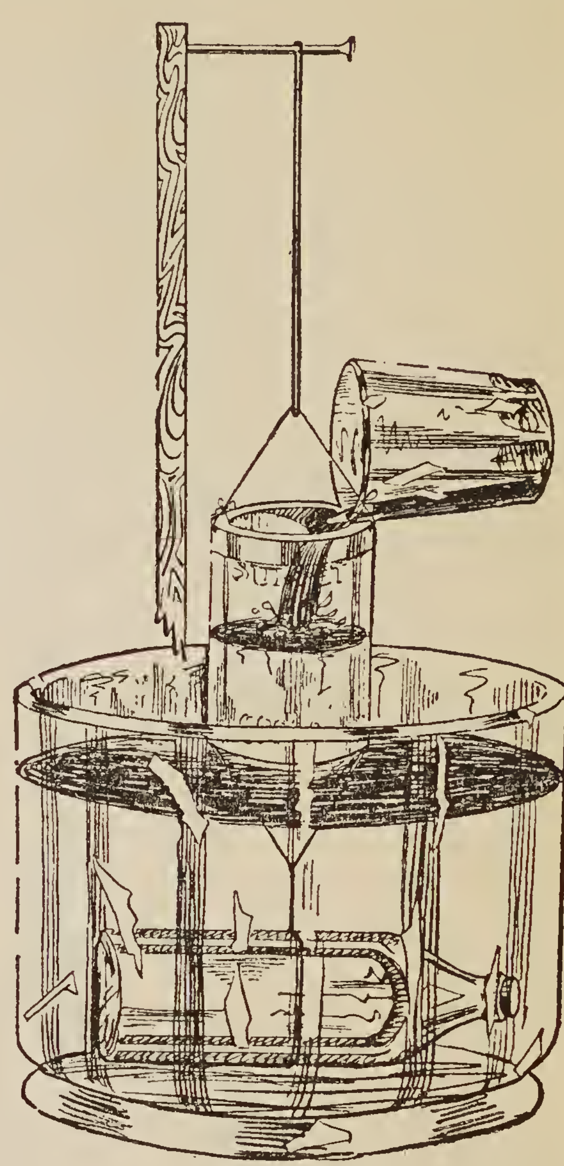


Fig. 104-4

A Body Which Sinks Loses Weight Equal to the Weight of Water It Displaces.

RAISING SUNKEN SHIPS

EXPERIMENT No. 38

To show how sunken ships are raised by means of air.

Sunken ships are raised by compressed air as illustrated in Figs. 105 and 106. Air is pumped into the ship until the ship and the air displace a weight of water slightly more than the weight of the ship; the buoyant force of the water then lifts the ship to the surface.

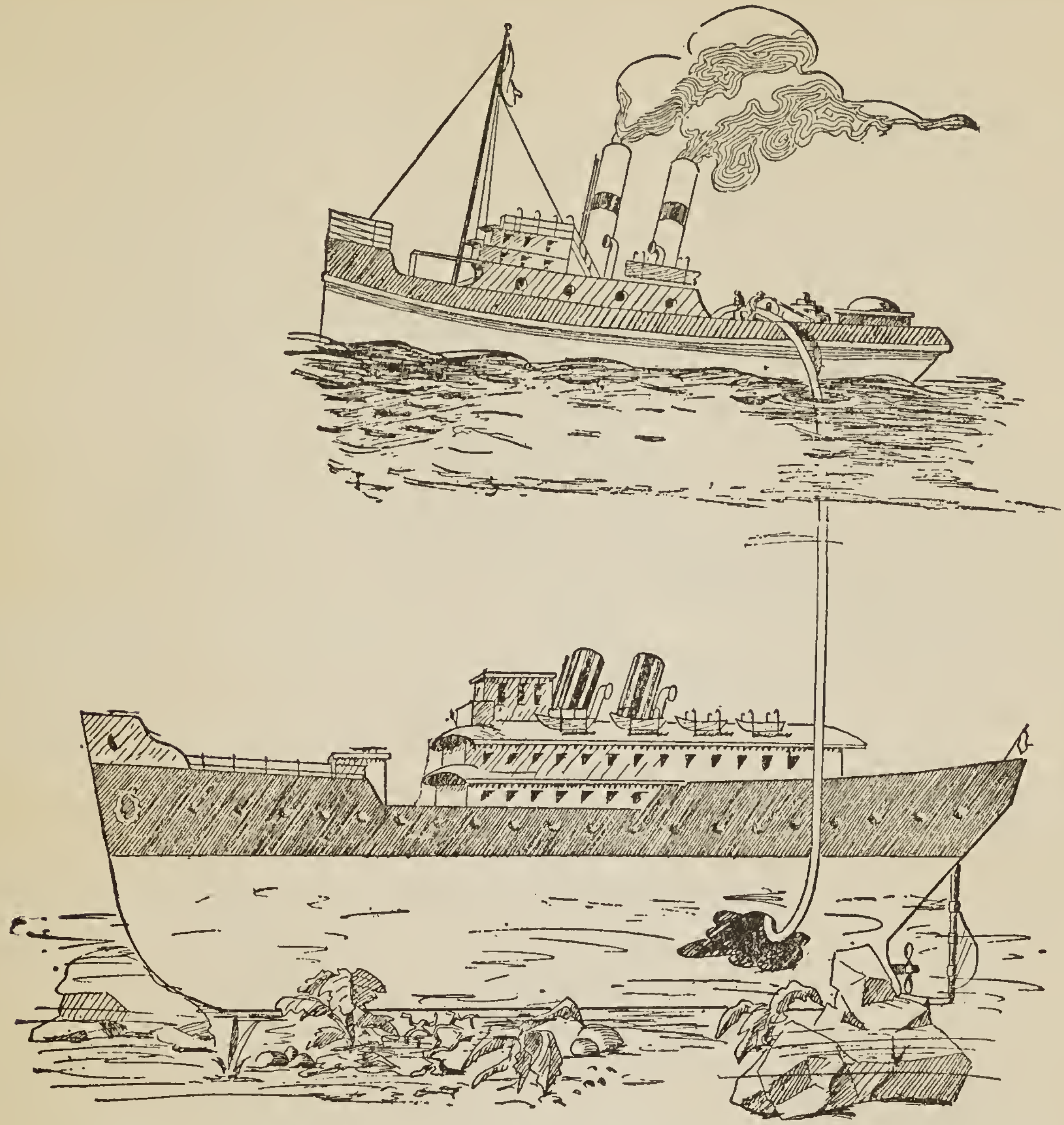


Fig. 105.—Pumping Air into a Sunken Ship to Force the Water Out.

Illustrate this with the apparatus shown in (1), Fig. 107. Fill the bottle with water to represent the sunken ship, submerge it in a pail of water, and blow air in through the hose. Does the ship float to the surface?

Sunken ships are also raised by means of large steel pontoons filled with air as shown in Fig. 108.

Illustrate this as shown in (2), Fig. 107. Use the bottle as the sunken ship and two empty tin cans of the same size as the pontoons. Punch nail holes in the opposite sides of the top edge of each tin can, connect them as shown, force air into them a little at a time in **equal** amounts. Is the ship raised nearly to the surface?

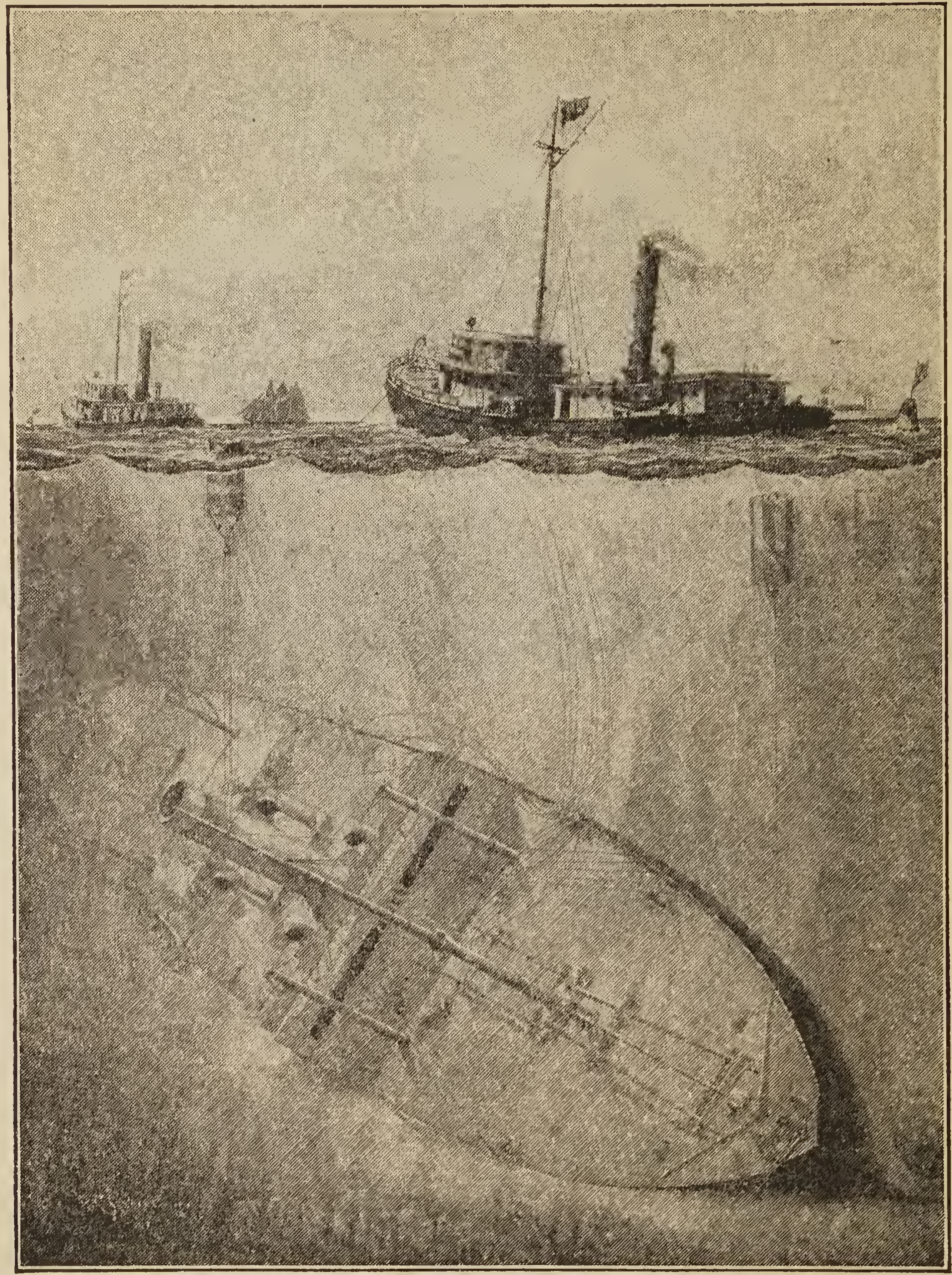


Fig. 106.—Showing How the Washingtonian was Raised by Compressed Air.
Courtesy of "The Scientific American"

Fig. 107.—Showing How Ships are Raised by Compressed Air.

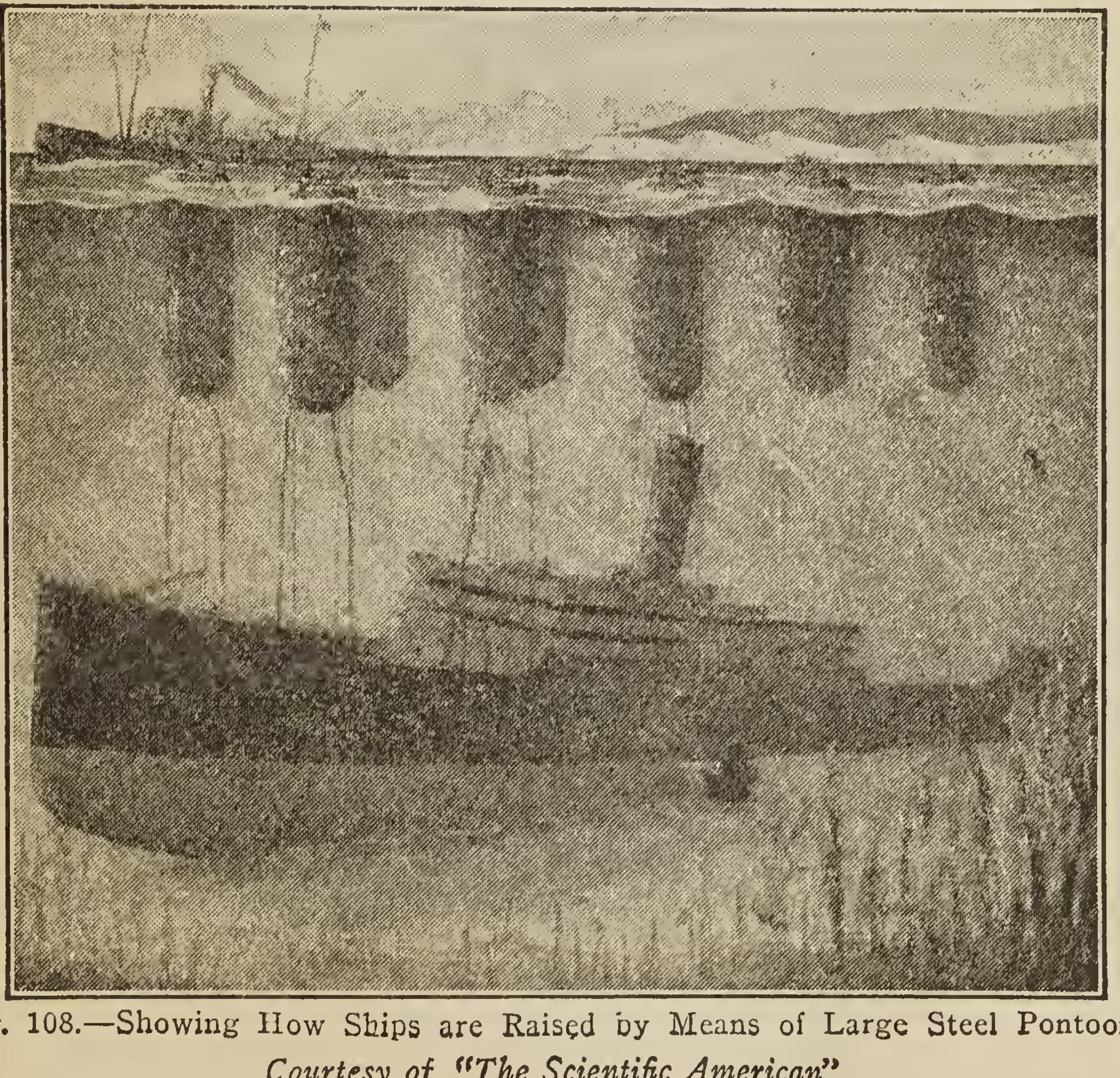


Fig. 108.—Showing How Ships are Raised by Means of Large Steel Pontoons.
Courtesy of "The Scientific American"

Note: The ship would be floated into shallow sheltered water in this way, then repaired by divers, and floated by compressed air as described; or a coffer dam would be built around it and the water pumped out; then the repaired ship would float when the water was admitted to the dam.

FLOATING DRY DOCKS

The floating dry dock, Fig. 109, is a huge steel or concrete trough shaped structure with hollow sides and with large tanks along the bottom. It is open at both ends and when the tanks T.T.T., Fig. 110 are filled with water it sinks to the water line L.L. The boat then sails into the dock and is securely braced, the water is pumped out of the tanks T.T.T., the dock rises until the water line is at W.W,, and lifts the ship above water.

The dry dock lifts its own weight and the weight of the ship because it displaces a weight of water equal to the combined weights.

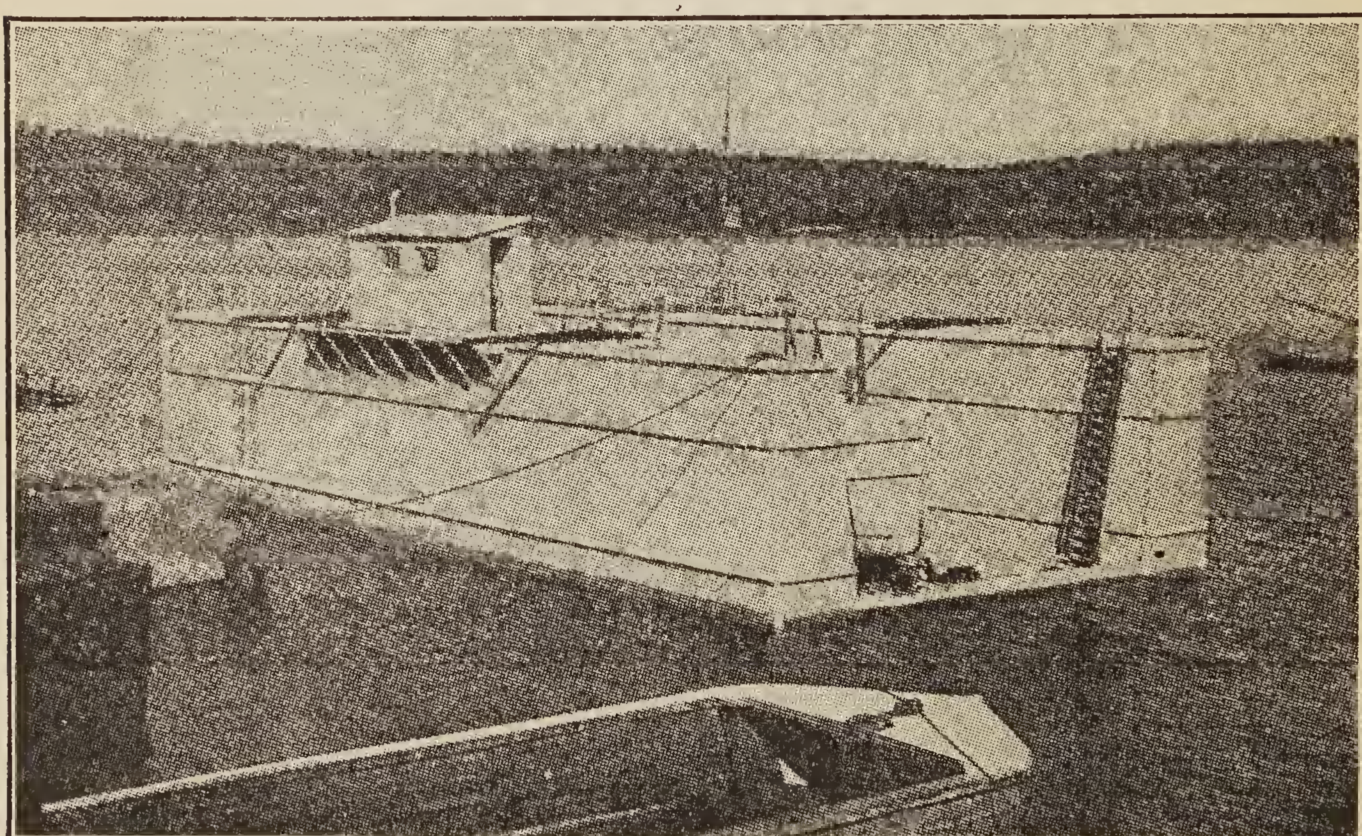


Fig. 109.—Floating Dry Dock
Courtesy of "The Scientific American"

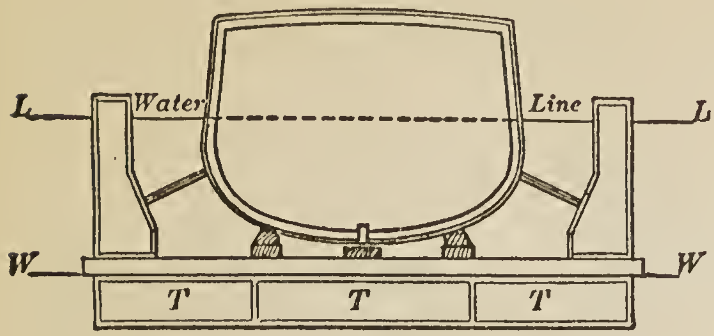


Fig. 110.—Cross Section of Floating Dry Dock and Ship.
Courtesy of The MacMillan Co.

When the ship has been repaired or when the barnacles have been scraped from its bottom and it is ready for sea, water is again admitted to the tanks, the dock sinks to the water line LL, and the ship sails out.

You will now make an experiment to illustrate the working of a floating dry dock.

EXPERIMENT No. 39

To make and operate a floating dry dock.

Use a flat cake pan to represent the dry dock, and the bottle to represent the ship.

Float the dock on water in a sink or wash basin and pour water into it until it floats with the top about 1 in. above water. This represents the real floating dry dock, with its tanks full, ready to receive the ship.

Float the bottle on the water in the dock. This represents the ship, in the dock and ready to be raised.

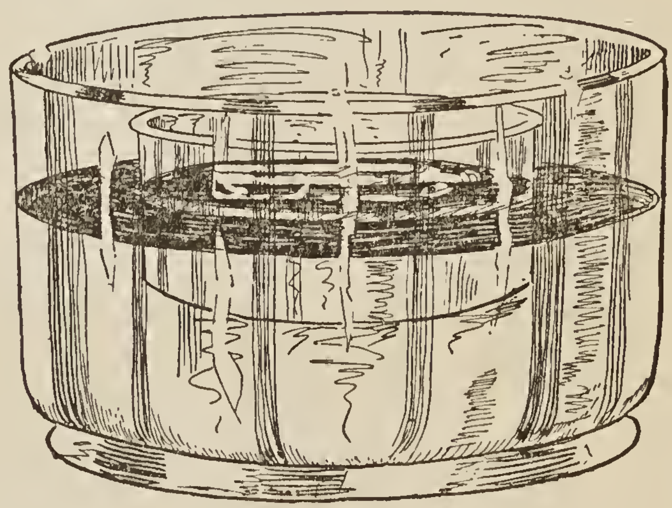


Fig. 111.—Illustrating the Working of a Floating Dry Dock.

Now siphon the water out of the dry dock and over the edge of the sink or wash basin. This represents the water being pumped out of the tanks of a real dry dock. Do you observe that both the dock and the ship are raised as the water is siphoned out? This shows how the dock and ship are raised when the water is pumped out of the tanks of a real dry dock.

Now siphon water from the sink into the floating dry dock. Do you observe that the dock and the ship sink as water enters the dock? This represents how the real dock sinks when water is admitted again to the ballast tanks.

THE GLASS SUBMARINE

EXPERIMENT No. 40

To make the glass submarine submerge and rise in water.

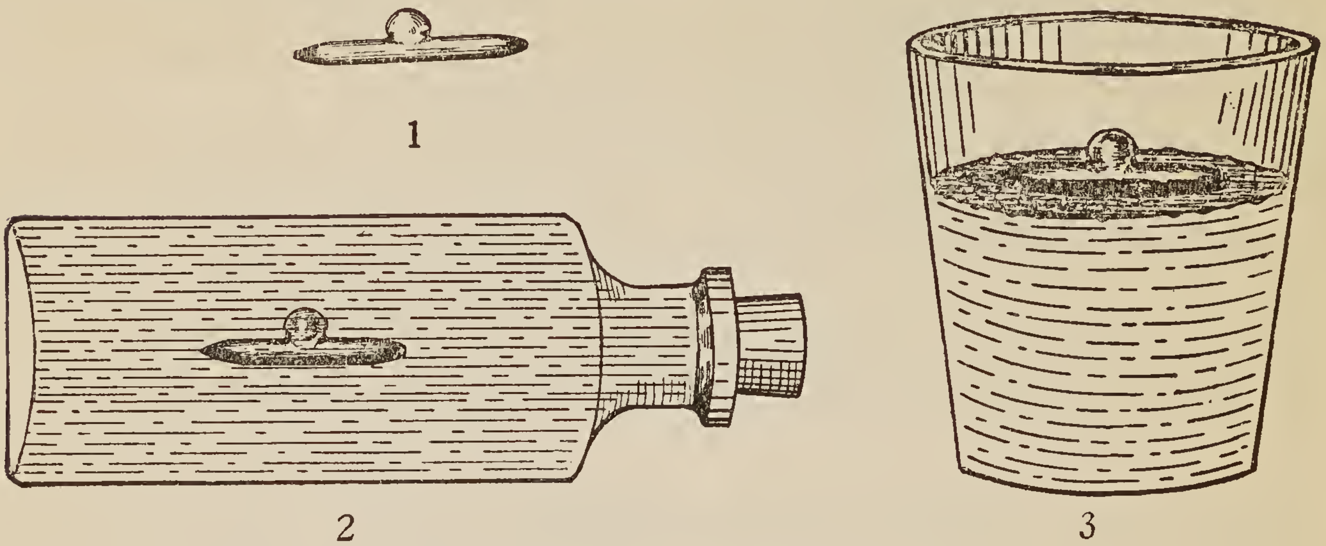


Fig. 112.—The Glass Submarine.

You will observe that the glass submarine (1), Fig. 112, is hollow and that it has a hole at the stern.

Place it in a tumbler of water. Does it float?

Place it, stern down, in the bottle full to overflowing with water, close the bottle, turn it on its side, and shove the stopper in hard. Does the submarine submerge? Withdraw the stopper slightly. Does the submarine rise and also move forward suddenly?

Repeat this with the bottle between your eyes and a light and observe the air in the submarine. Is the air compressed when you shove the stopper in, and does it expand when you withdraw the stopper?

The submarine floats in the tumbler because it is lighter than an equal volume of water. It sinks in the bottle when you force the stopper in because sufficient water is forced in to make it heavier than an equal volume of water. It rises when you release the stopper because the air expands and forces sufficient water out to make it again lighter than its own volume of water.

Water is nearly incompressible but air is very compressible and when you shove the stopper in you compress the air but not the water.

Find a larger bottle and repeat these experiments.

The submarine moves forward when you withdraw the stopper because the expanding air shoots a stream of water to the rear through the stern and this drives the submarine forward.

Illustrate this with the apparatus Fig. 113. Does the stream in one direction under water force the nozzle in the other and make it writhe like a snake?

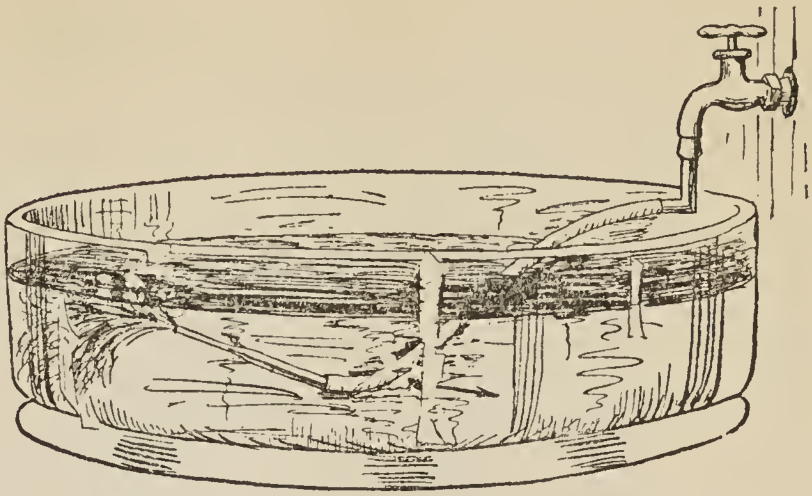


Fig. 113.—The Water Issuing from the Nozzle in One Direction Drives the Nozzle in the Other Direction.

RUNNING WATER

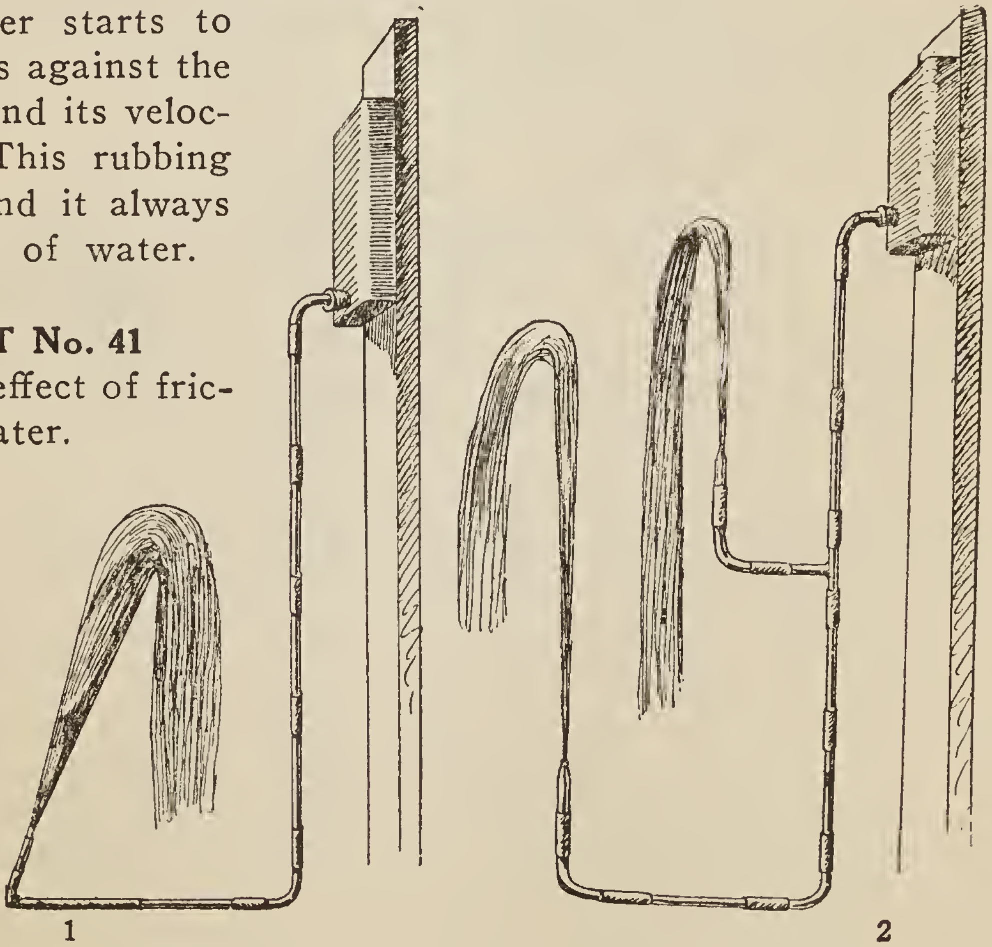
FRICTION

As soon as water starts to run in a pipe it rubs against the inside of the pipe and its velocity is decreased. This rubbing is called **friction** and it always decreases the flow of water.

EXPERIMENT No. 41

To illustrate the effect of friction on running water.

Use the apparatus, (1), Fig. 114. Raise and lower the tank. Do you find that the stream from the nozzle never reaches the level of the water surface in the tank?



1 2

Fig. 114.—Friction Decreases the Height of Streams.

It does not do so because the friction in the tubes and nozzle decrease its velocity.

Use the apparatus (2), Fig. 114. Is the lower stream longer than the upper, but do you find that it does not reach as high as the upper stream? It does not, because the velocity of the water in the lower tube and nozzle is greater and therefore the friction is greater.
Use the apparatus, Fig. 115. Allow the water to run into the tumbler for exactly 15 seconds and observe the amount, then close the coupling above the tee, empty the water back into the tank, transfer the elbow to the end coupling, and allow the water to run into the tumbler from the end for exactly 15 seconds. Is the flow of water less from the end? It is less because the friction in the extra pipes decreases its velocity.

It is a matter of the greatest importance that friction be taken into consideration in planning the piping for any system of water supply or water power. The facts regarding it may be stated briefly as follows:

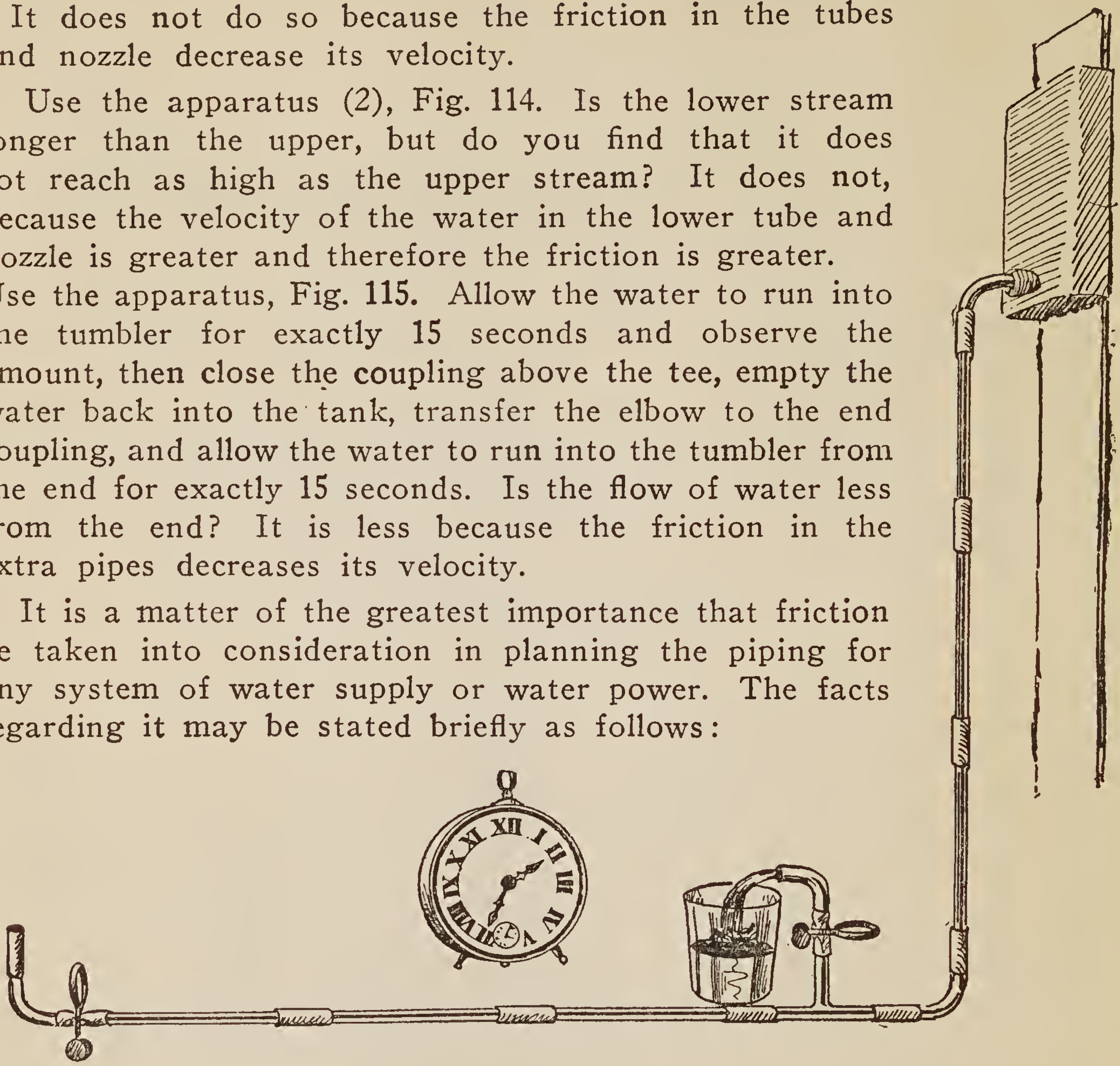


Fig. 115.—Showing That Friction Decreases the Velocity of Water in Pipes.

The friction of water in pipes:

(1) Is greater in long pipes than in short pipes of the same size.

(2) Is greater in rough pipes than in smooth pipes of the same size.

(3) Is greater when the water is moving rapidly than when it is moving slowly .

(4) Is greater in small pipes than in large pipes of the same length.

NOZZLES

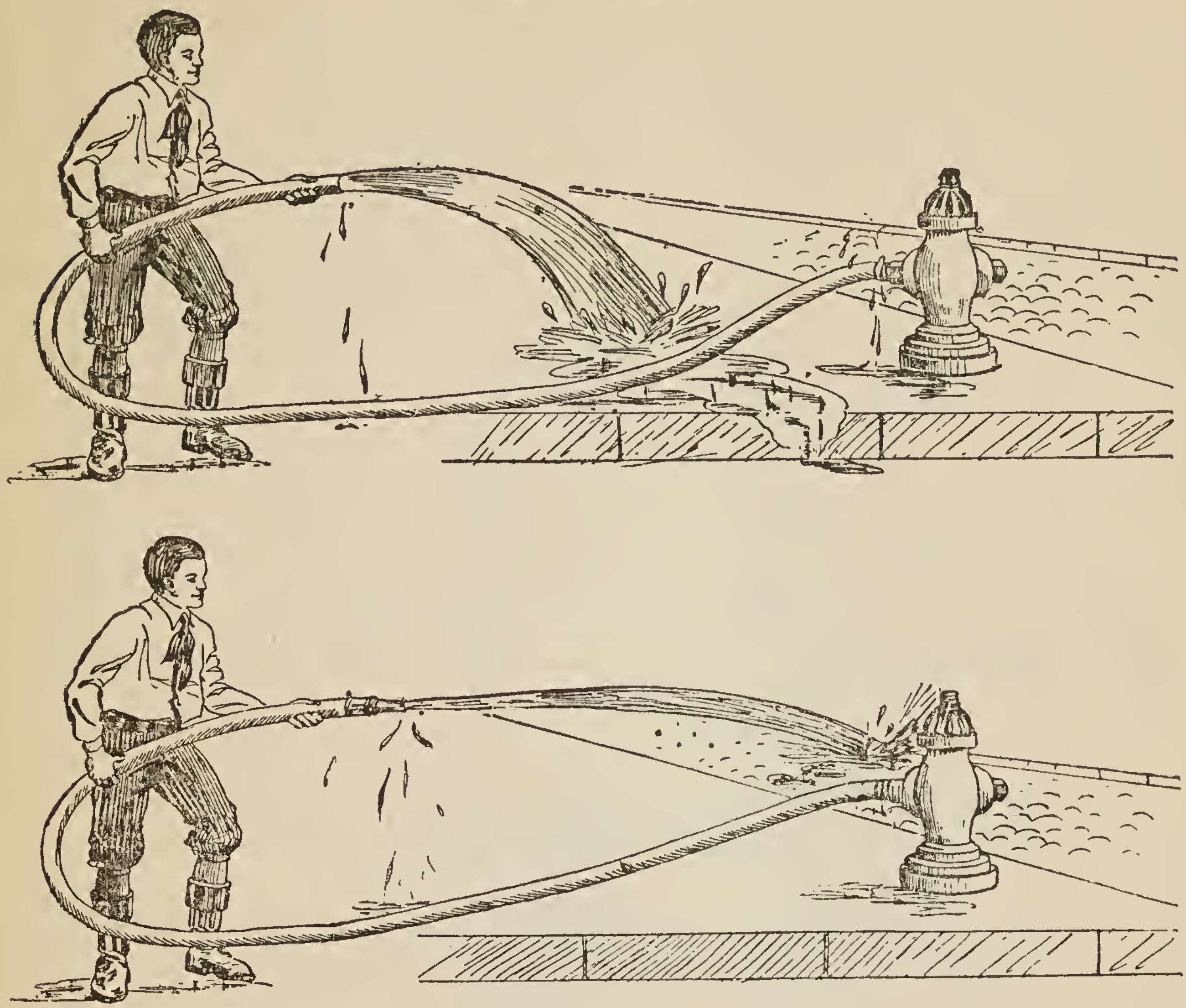


Fig. 116.—Boy Puts More Water on the Road in a Given Time Without a Nozzle Than With One.

When you have been watering the road or garden you have probably noticed that the stream is longer when you use a nozzle than when you simply let the water flow from the end of the hose. Have you noticed, however, that you put less water on the road or garden in a given time with a nozzle than without?

EXPERIMENT No. 42

To show why the stream is longer with a nozzle than without.

Use the apparatus (1), Fig. 117. Is the stream short and is the pressure low? Place a nozzle in the coupling (2), Fig. 117. Is the stream long and is the pressure high?

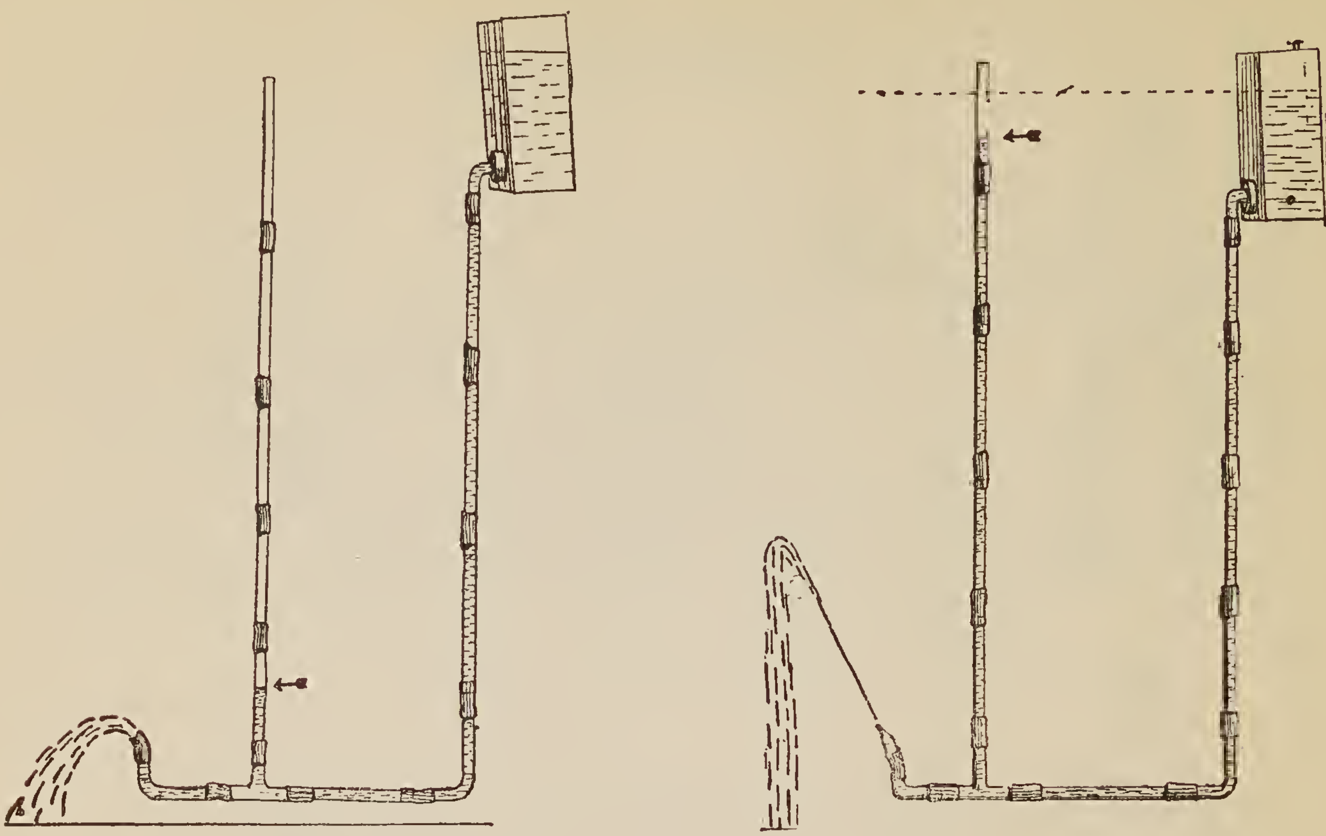


Fig. 117 - 1.—The Pressure is Low Behind a Large Nozzle.
Fig. 117 - 2.—The Pressure is High Behind a Small Nozzle.

You have shown here that the stream from a nozzle is longer than from the hose because the pressure behind it is greater.

The pressure at any point in a pipe carrying running water is proportional to: first, the height above the point of the water in the tank; and second, to the fraction of the total resistance the running water encounters beyond the point. The pressure behind the nozzle in (2) is great because the resistance the water encounters in the nozzle is great.

EXPERIMENT No. 43

To show that you put less water on a road in a given time with a nozzle than without.

Use the apparatus, Fig. 118, allow the water to run from the end of the hose into the tumbler for exactly 15 seconds and observe the amount, then insert the nozzle and repeat. Is the flow less with the nozzle than without?

VELOCITY OF FLOW

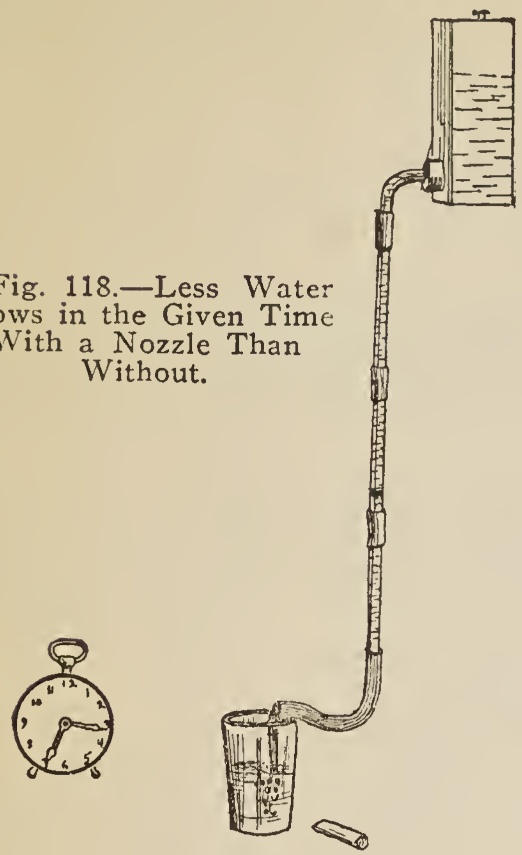
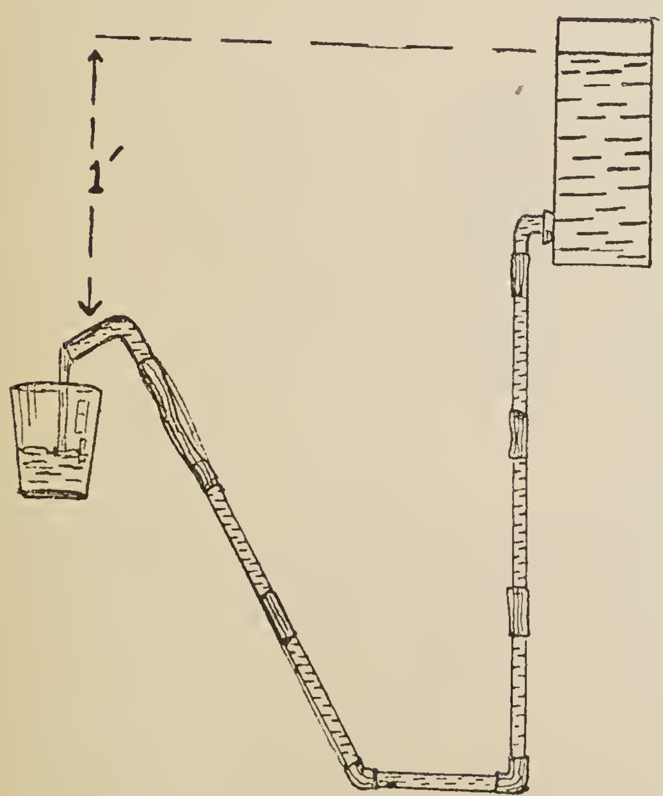


Fig. 118.—Less Water Flows in the Given Time With a Nozzle Than Without.



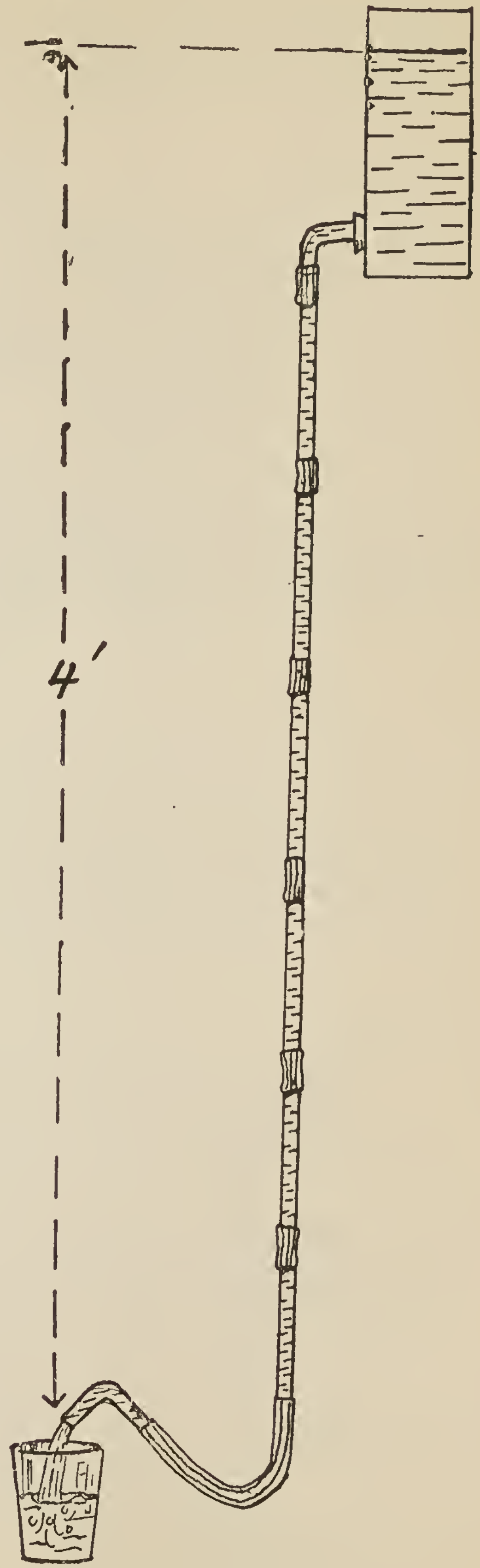


Fig. 119.—The Velocity of Flow is Double When the Head is Made Four Times As Great.

You might think that the velocity of water from a nozzle would be doubled when you double the height of the water in the tank above the nozzle. You will show, however, that you must make the height four times as great to double the velocity.

EXPERIMENT No. 44

To show that the velocity of water is doubled when the head is made four times as great.

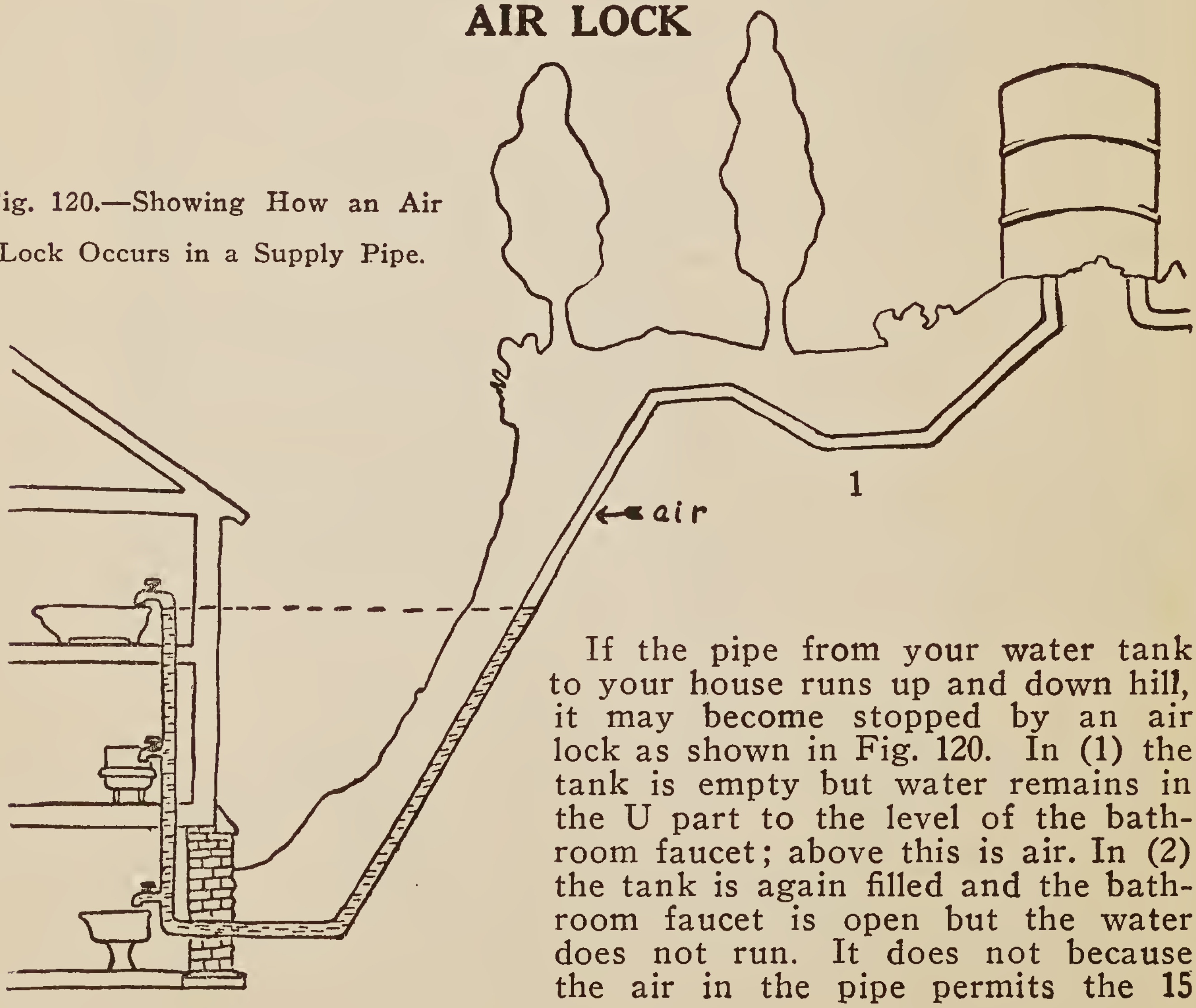
Use the apparatus, Fig. 119. Allow the water to flow into the tumbler for 15 seconds with the head exactly one foot, observe the amount carefully, then repeat with the head exactly four feet. Is the amount doubled?

The head is the vertical distance the water surface in the tank is above the nozzle opening.

The velocity of water in a pipe varies as the square root of the head. That is, if you start with a head of 1 foot, and increase the head to 4 feet the velocity is doubled, $\sqrt{4} = 2$; if you increase the head to 9 feet the velocity is trebbled $\sqrt{9} = 3$, and so on.

AIR LOCK

Fig. 120.—Showing How an Air Lock Occurs in a Supply Pipe.



If the pipe from your water tank to your house runs up and down hill, it may become stopped by an air lock as shown in Fig. 120. In (1) the tank is empty but water remains in the U part to the level of the bathroom faucet; above this is air. In (2) the tank is again filled and the bathroom faucet is open but the water does not run. It does not because the air in the pipe permits the 15

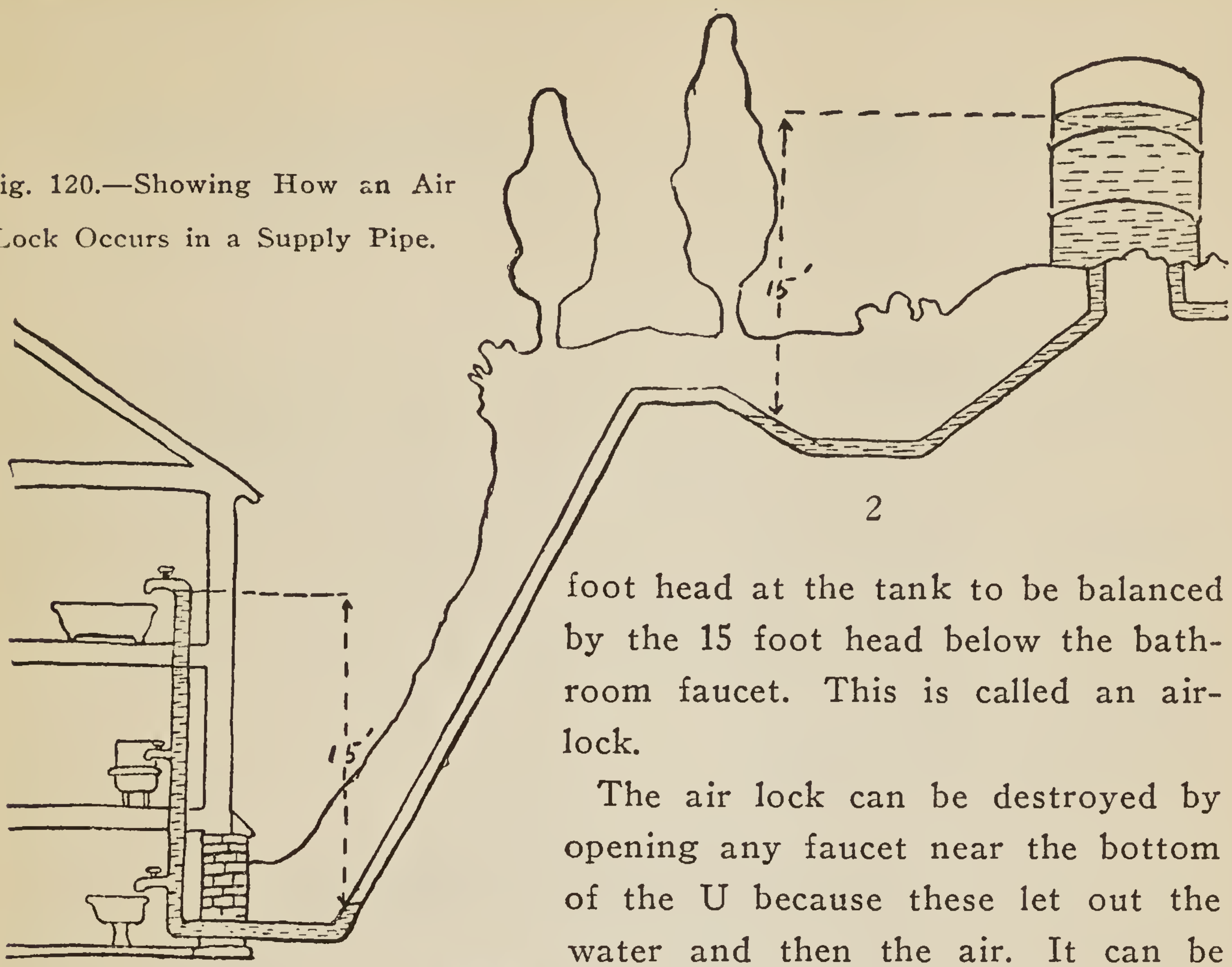


Fig. 120.—Showing How an Air Lock Occurs in a Supply Pipe.

foot head at the tank to be balanced by the 15 foot head below the bathroom faucet. This is called an air-lock.

The air lock can be destroyed by opening any faucet near the bottom of the U because these let out the water and then the air. It can be destroyed here by opening the basement faucet.

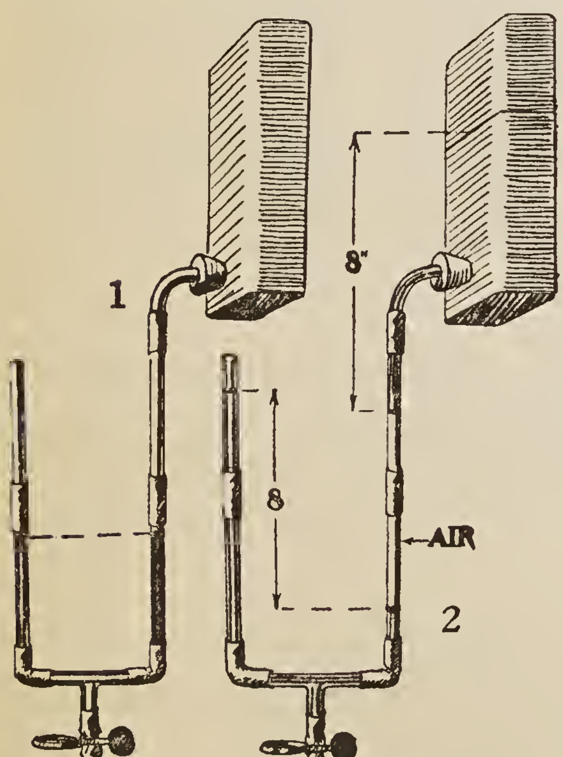


Fig. 121.—Illustrating an Air-Lock in Pipes

EXPERIMENT No. 45

To illustrate an air lock.

Use the apparatus, Fig. 121. In (1) the tank is empty and the U is half full of water. In (2) the tank is filled but the water does not run. It is air locked because the air permits the 8 inch head in the U to balance the 8 inch head at the tank.

Open the tee. Is the air let out? Close the tee. Does the water flow, that is, is the air lock destroyed.?

PNEUMATIC ENGINEERING

Pneumatic engineering is the engineering which deals with air and other gases. You have already used two pneumatic appliances in the section on hydraulic engineering, namely, the siphon and the pump; these are pneumatic and also hydraulic appliances. You have also made some experiments to show that the atmosphere exerts pressure; you will begin your work in pneumatic engineering by making further experiments along this line.

ATMOSPHERIC PRESSURE

EXPERIMENT No. 46

To show that the atmosphere exerts pressure.

The Magdeburg hemispheres, (1) Fig. 122, are made of metal, are hollow, and are ground smooth around the edge so that they fit together air-tight. When the air is pumped out, through the handle on one side, they are hard to pull apart. The original hemispheres, (2) Fig. 122, were 14 inches in diameter and required eight horses on each side to pull them apart. When the air is pumped out there is nothing inside the hemispheres to exert pressure outward and the pressure of the atmosphere holds them together.

Show this with (1), Fig. 123. Pull the handle up and there is very little air inside to exert pressure outward. Pull out the end stopper. Does the atmosphere make this rather difficult?

(1) Fig. 122

(2) Fig. 122.—The First Magdeburg Hemisphere.
Courtesy of The MacMillan Co.

Show it also with (2). Fill the quart sealer one third full of hot water, put on the rubber ring and the cover but do not seal, place the sealer in a saucepan of salt water, heat until the water in sealer has boiled for one or two minutes, seal and stand aside until quite cold. Unseal and try to lift the cover. Is it difficult?

The steam formed in the sealer drives out the air and when the steam condenses there is a vacuum above the water in the sealer. There is then no upward pressure under the cover and the atmospheric pressure on top makes it difficult to lift the cover.

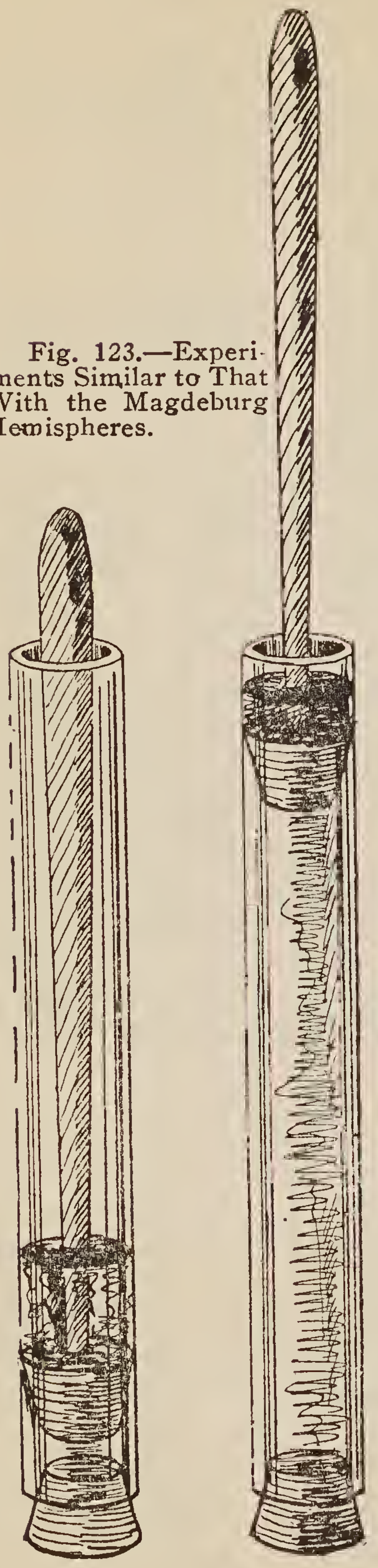
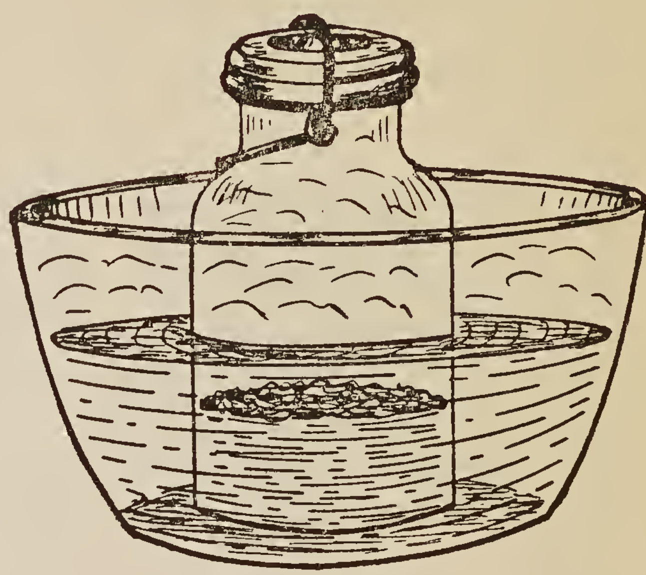


Fig. 123.—Experiments Similar to That With the Magdeburg Hemispheres.

1



2

Fig. 123.—Experiments Similar to That With the Magdeburg Hemispheres.

When the plunger is raised in the tube, (1), Fig. 124, the atmospheric pressure on the outside forces the sheet of rubber in.

Illustrate this also by means of (2). Fig. 124. Suck air out of the tube and close the hose with a clip. Does the atmosphere force the rubber in? Turn the rubber in all directions. Is the pressure of the atmosphere equal in all directions.

A most striking method of showing that the atmosphere exerts pressure is shown in Fig. 125. A little water is placed in an empty syrup can and boiled until the steam comes out for one or two minuts. The can is then closed air tight and inverted in a dish of cold water. In a short time the can suddenly collapses.

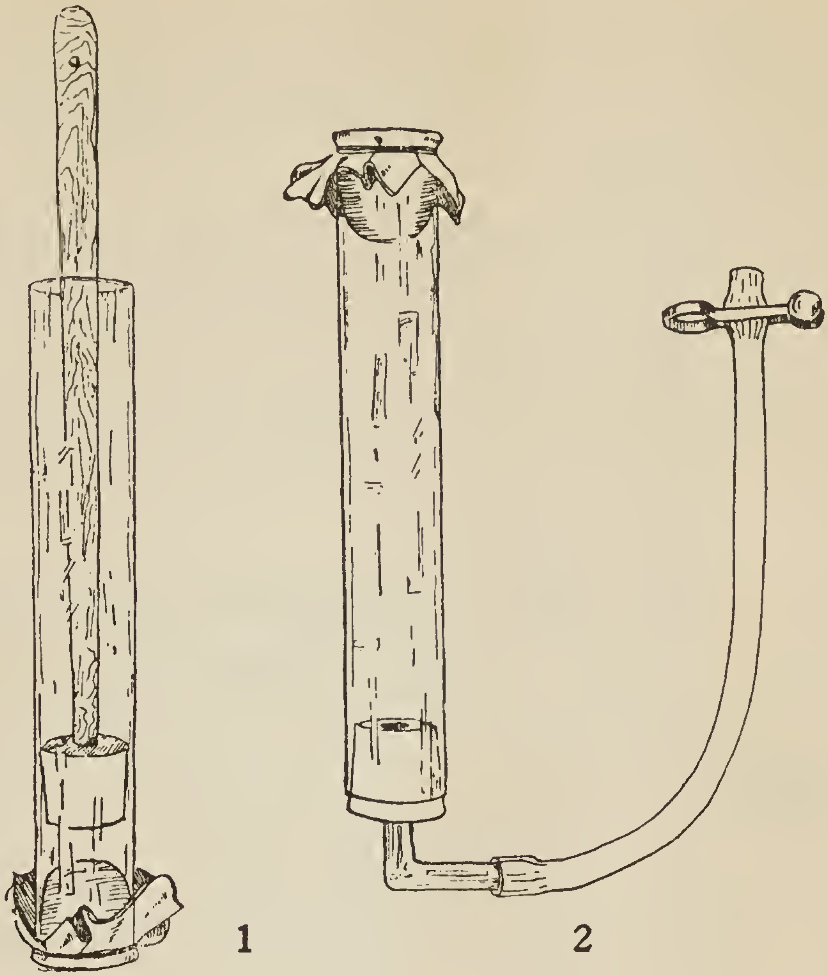


Fig. 124.—The Atmosphere Forces the Rubber Sheet In.

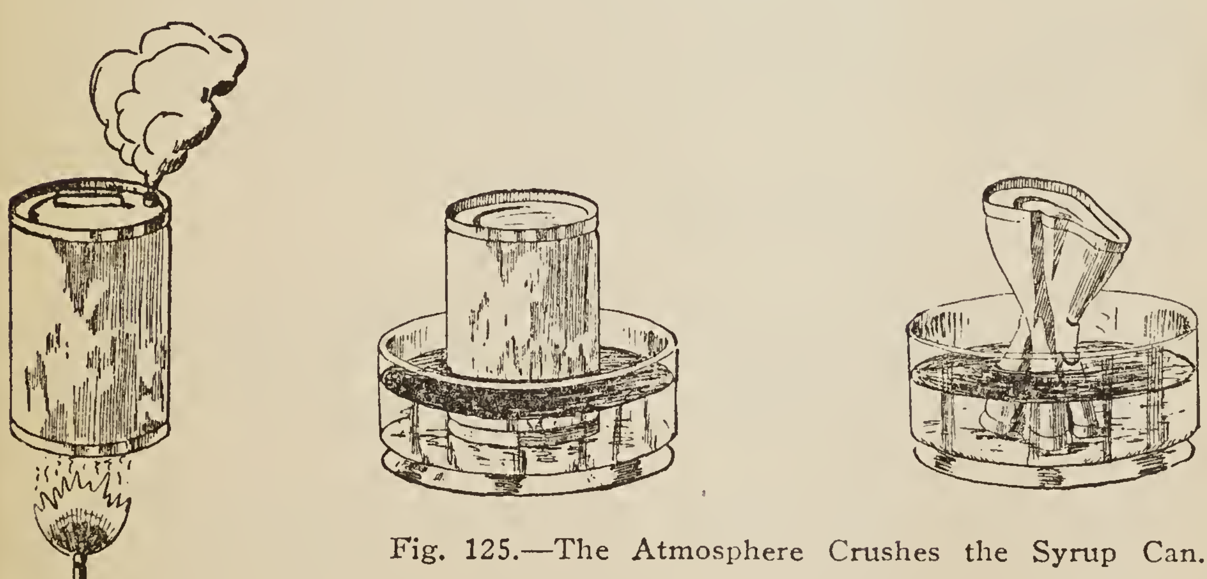


Fig. 125.—The Atmosphere Crushes the Syrup Can.

The reason for this is as follows: when the steam has driven out the air there is nothing left in the can but water and steam, and when

the steam condenses in the closed can, there is nothing in the space above the water, to exert pressure outward and the can must stand the whole pressure of the atmosphere. If it is not strong enough to do this, it collapses.

Beg or buy a gallon syrup can and try this experiment, it will certainly surprise you. Be sure the opening is covered with water when you invert the can in cold water because the water will help to make the opening air-tight.

You cannot make this experiment with a glass bottle because the glass is strong enough to support the atmosphere.

HOW ATMOSPHERIC PRESSURE WAS FIRST MEASURED

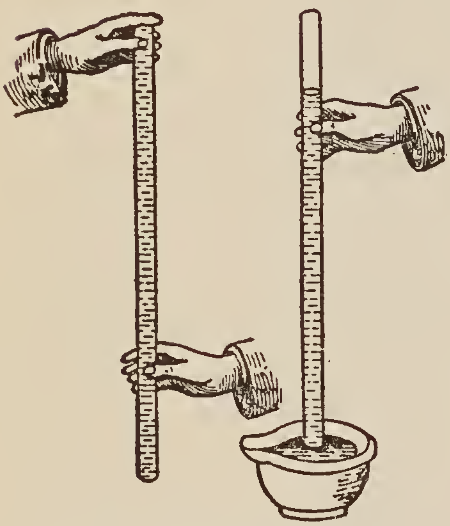


Fig. 126.—Torricelli's Experiment.
Courtesy of The MacMillan Co.

The pressure of the atmosphere was first measured by an Italian named Torricelli in 1643, with apparatus similar to that shown in Fig. 126. His experiment was essentially as follows: A glass tube, 3 feet long and closed at one end, was completely filled with mercury (quicksilver) to expel the air; the open end, closed with the finger, was then inverted over a dish of mercury, and the finger was removed under mercury.

He found that some of the mercury came out of the tube but that a column remained to a height of about 30 inches above the surface of the mercury in the dish.

Since no air enters the tube, the space above the mercury in the tube has nothing in it, that is, it is a vacuum. There is, therefore, no pressure downward on the surface of the mercury in the tube, and the pressure of the atmosphere downward on the surface of the mercury in the dish supports the column of mercury in the tube.

HOW THE PRESSURE OF THE ATMOSPHERE IS MEASURED

If this experiment is repeated with the tube shown in Fig. 127, the top of the mercury in the long closed tube is 30 inches above the top of the mercury in the short open tube. Since, as you will show shortly, this height is independent of the area of cross section of the tube, we can consider this to be just 1 square inch.

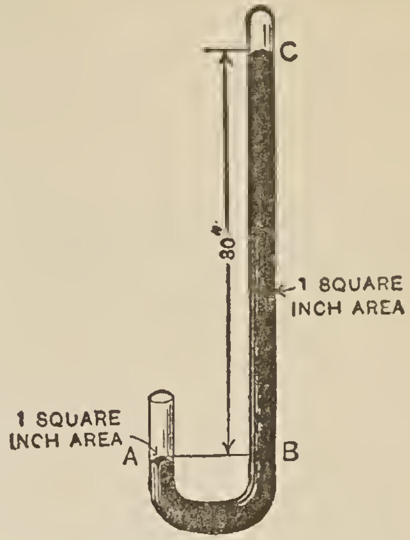


Fig. 127.—Calculating the Atmospheric Pressure on one square inch
Courtesy of The MacMillan Co.

The pressure of the atmosphere on 1 square inch at A, then, supports a column of mercury BC which is 1 square inch in area and 30 inches high, that is, it supports 30 cubic inches of mercury.

Now 1 cubic inch of mercury weighs .49 lbs. (nearly ½ lb.) and 30 cubic inches of mercury weigh .49 x 30 = 14.7 lbs. The pressure of the atmosphere is therefore 14.7 lbs. per square inch, (nearly 15 lbs. per square inch).

It is a very astonishing fact that the atmosphere exerts 14.7 lbs. pressure on each square inch of every thing at the surface of the earth. It is at first almost unbelieveable, but you have already made experiments which illustrate this pressure and you will make others as you proceed.

EXPERIMENT No. 47

To measure the pressure of the atmosphere.

If you have a spring balance you can measure the pressure of the atmosphere directly with the apparatus, Fig. 128, as follows.

The diameter of the plunger is a little over ⅝ inches and therefore its area is 3/10 square inch. If then the pressure of the atmosphere is 15 lbs. on 1 square inch it is 15 x 3/10 = 4½ lbs. on 3/10 square inch.

Soap the plunger well to make it slippery, shove it about ¾ way into the tube, fill the remaining ¼ of the tube with water, and insert a solid rubber stopper in this end, (1). Now turn the tube so that the plunger handle points vertically upward, and pour a little water in above the plunger to make it air-tight, (2).

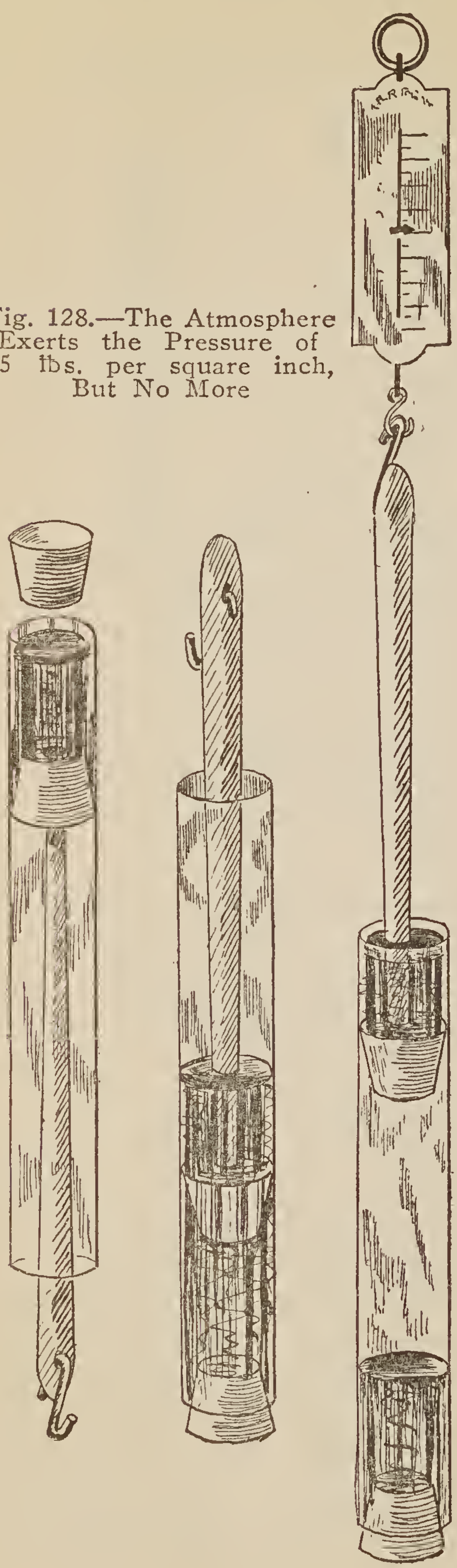


Fig. 128.—The Atmosphere Exerts the Pressure of 15 lbs. per square inch, But No More

1 2 3

Now to measure the pressure of the atmosphere, attach the plunger handle to a spring balance, hold the tube firmly against the table, and ask your partner to pull upward on the spring balance while you observe the pull recorded on the balance, (3).

Ask him to lift the balance slowly until the plunger is about two inches above the water, then ask him to allow the balance to go back slowly until the plunger is only about 1 inch above the water. While he is doing this you must read the average pull on the balance.

Do you find this average pull to be 72 ozs. or 4½ lbs?

Note: While your partner is raising the plunger, the friction of the plunger against the sides of the tube is working against the balance and the pull will be over 4½ lbs; but while he is lowering the plunger, the friction will be working with the balance and the pull will be less than 4½ lbs. The average will be about 4½ lbs.

You have shown here that the pressure of the atmosphere is 4½ lbs. on 3/10 sq. in. or 4½ x 10/3 = 15 lbs. on 1 square inch.

THE BAROMETER

The barometer, Fig. 129, is the chief instrument used by the Weather Bureau in forecasting the weather. It is an apparatus similar to that used by Torricelli in his experiment. The pressure of the atmosphere on the mercury in the open tube or cup supports a column of mercury about

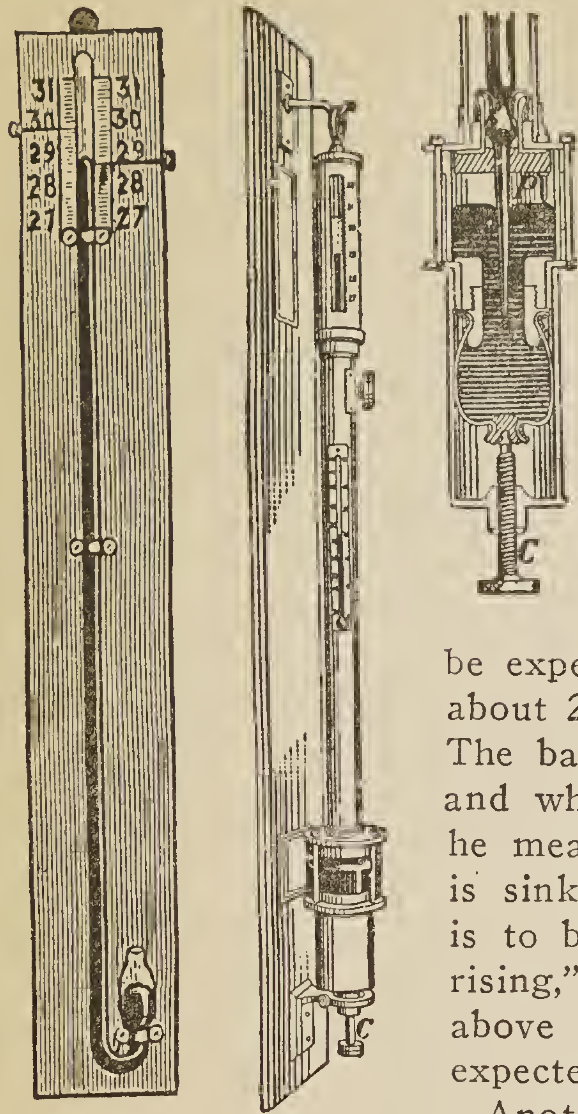


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Fig. 129.—Barometers

1-Courtesy of the MacMillan Co.

2-From the "Ontario High School Physics". By Permission of the Publishers

30 in. high in the long closed tube. The pressure of the atmosphere varies from hour to hour and the height of the mercury column varies with it. Weather forecasts are based on this variation.

It has been found that when the mercury falls much below 30 in., because the atmospheric pressure is low, bad weather may be expected; and when the mercury rises much above 30 inches, because the atmospheric pressure is high, good weather may be expected. The extreme variations are from about 29 in. to 31 in.

The barometer (2) is the type used on ships, and when a sailor says "the glass is falling" he means that the mercury in the glass tube is sinking below 30 in. and that bad weather is to be expected; when he says "the glass is rising," he means that the mercury is rising above 30 in. and that fine weather is to be expected.

Another type of barometer is shown in Fig. 130. It is called an aneroid barometer because it contains no liquid. It has a flat, round, air-tight metal box from which the air is ex-exhausted. The atmospheric pressure would force together the top and bottom of this box if they were not kept apart by the strong spring shown

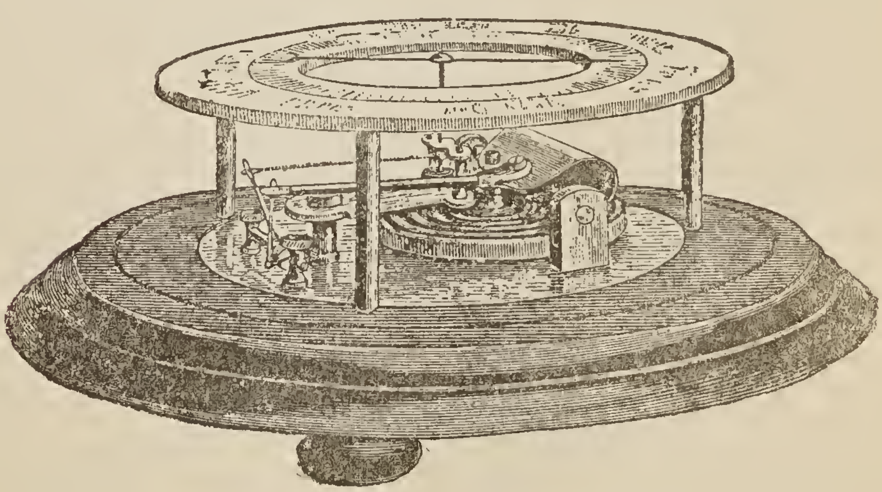
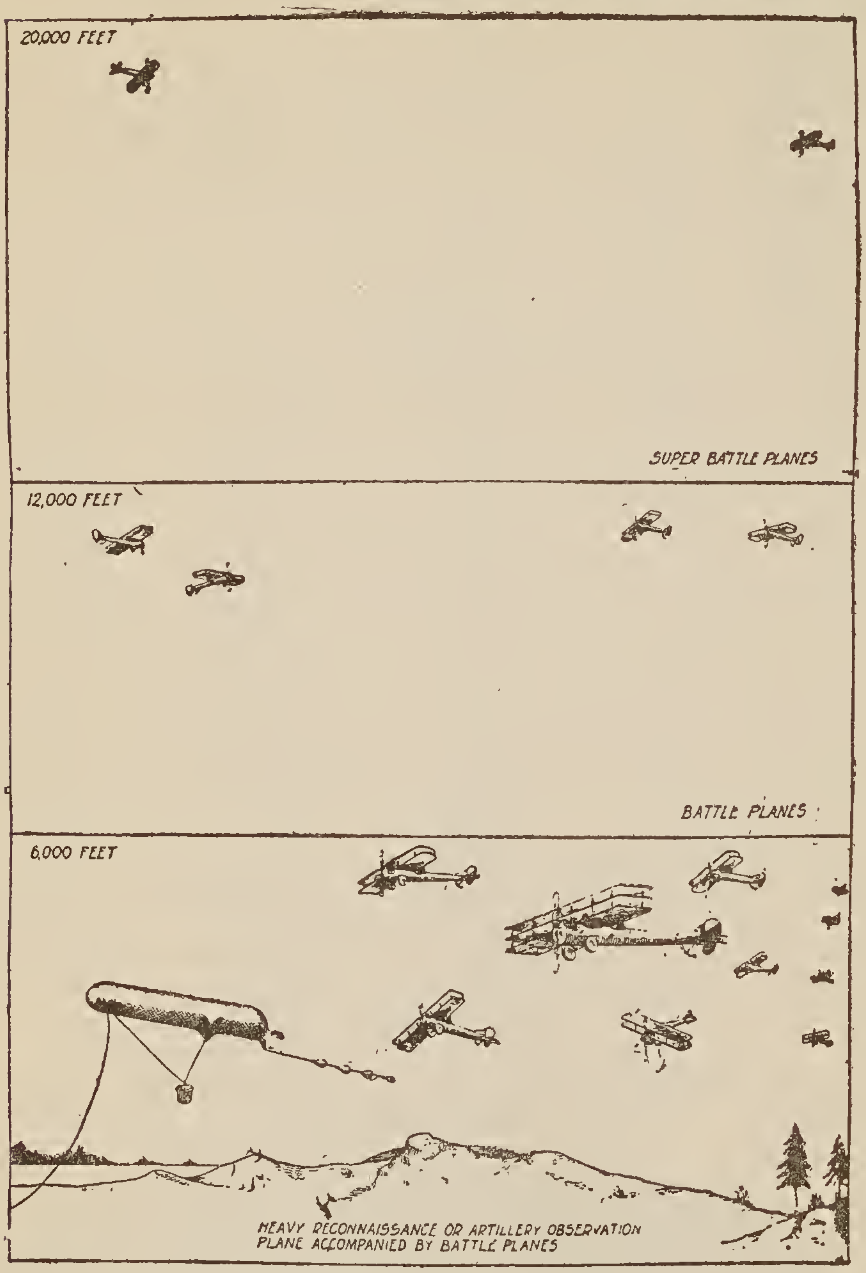


Fig. 130

Fig. 130.—Aneroid Barometer
Courtesy of The MacMillan Co.

above the box. If the atmospheric pressure increases, the spring is forced down; if the pressure decreases, the spring rises. The movements are very small, but they are magnified by levers and are communicated to the pointer by means of a rack and pinion.

HOW AIRMEN KNOW THEIR ALTITUDE
THE ALTITUDE GAUGE



Air Zones of Modern Battle (1918)

Fig. 131.—Air Zones

Courtesy of "The World's Work", Garden City, N. Y.

The air zones of a modern battle are illustrated in Fig. 131 and the altitude guage by means of which the airmen know their height is shown in Fig. 132. This altitude gauge is a recording aneroid barometer called a barograph. It records the height of the airplane in feet and is suspended free of the airplane by four elastic straps which protect it, to some extent, from the vibration of the machine.

The construction of the barograph is as follows. It has five or six flat metal boxes, exhausted of air, similar to the box in the ordinary aneroid. These boxes are expanded by a strong spring, as the height increases, and this movement is communicated to the long pointer. On the end of the pointer there is a pen, with a supply of ink, which bears against a sheet of paper on a drum revolved by clockwork. The pen makes a continuous record on the paper of the height in feet.

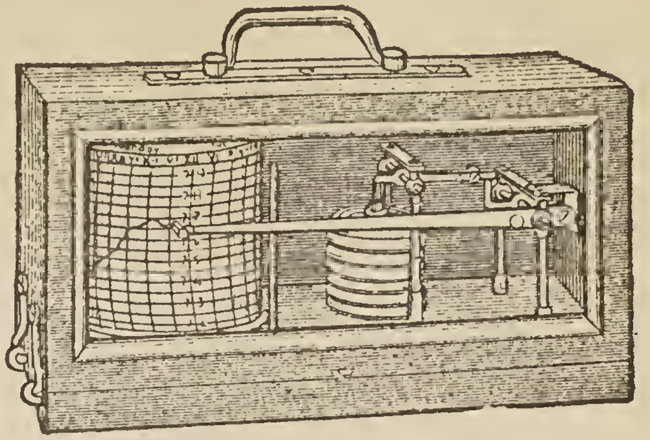


Fig. 132.—The Altitude Gauge or Barograph

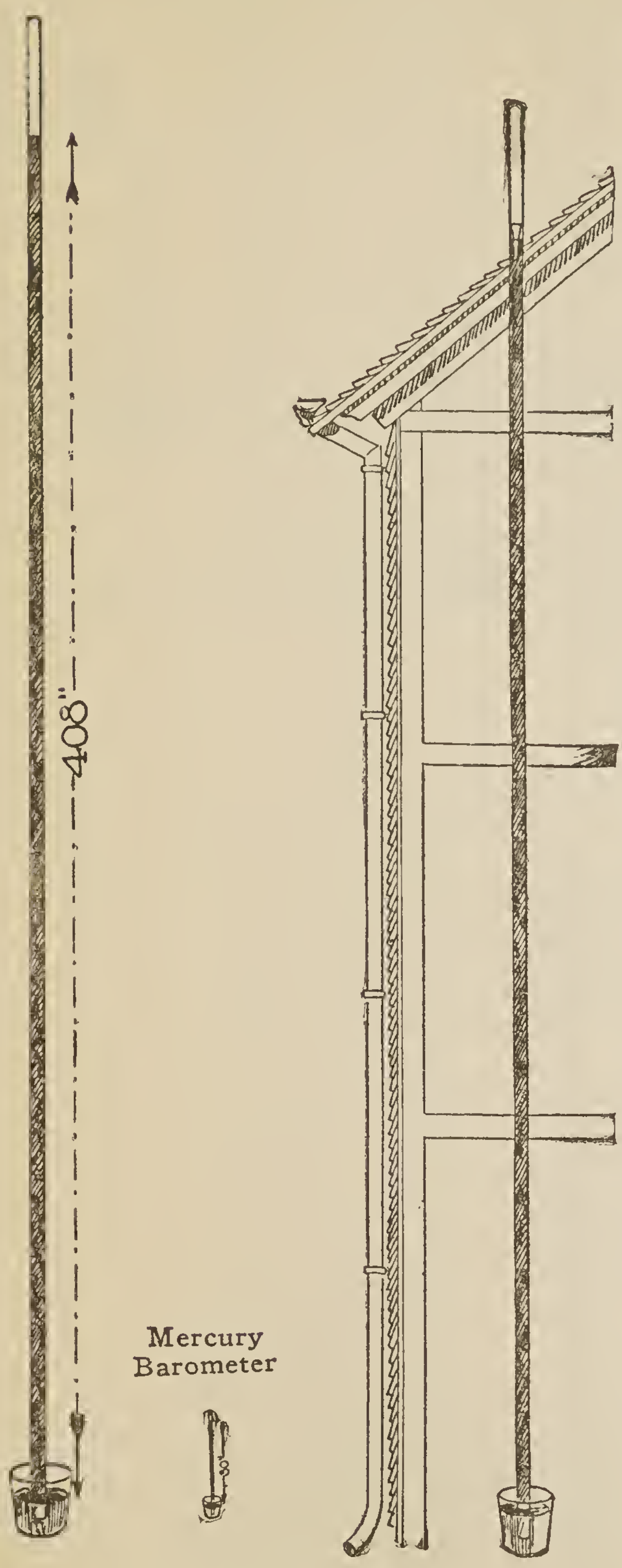


Fig. 133.—Water Barometer

THE WATER BAROMETER

Any liquid can be used in a barometer but liquids lighter than mercury require longer tubes. This is true of the water barometer. Mercury is 13.6 times as heavy as water and since the atmosphere supports a column of mercury 30 in. high it will support a column of water $13.6 \times 30 = 408$ in. high, that is, a column $408/12 = 34$ feet high.

Otto von Guericke, the inventor of the Magdeburg hemispheres, made a water barometer in 1650, and had it so arranged that the top of the tube stuck up through the roof of his house. He had a small wooden figure floating on the water in the tube and in fine weather, when the water column rose, the figure rose above the roof, but in bad weather the figure retired from sight. This frightened and mystified his neighbors very much and they accused him of being in league with the evil one.

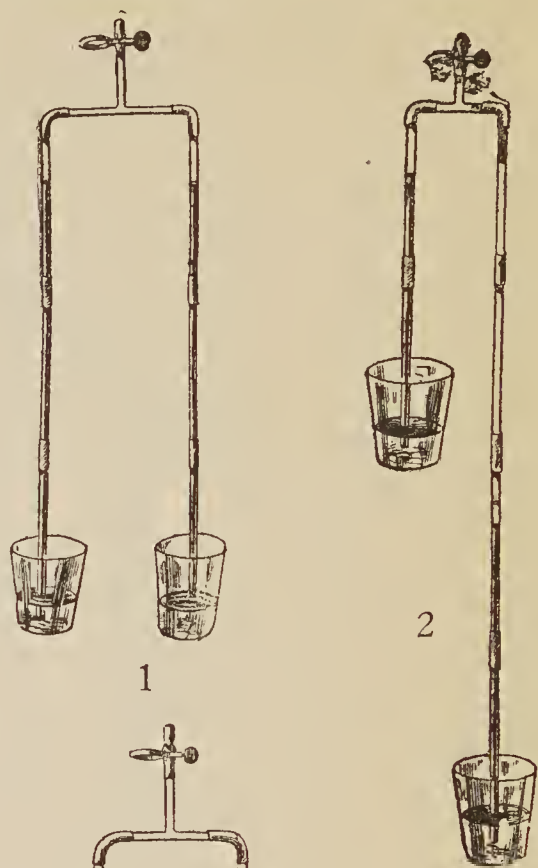
EXPERIMENT No. 48

To show that the vertical height to which the atmosphere will lift water in a tube is independent of the length or slant of the tube.

Make the experiments (1), (2) and (3), Fig. 134. Suck air out through the upper coupling on the tee and close the clip.

Is the vertical height of the water in one tube above the water in the tumbler always the same as that in the other?

Make experiments of **your own.**



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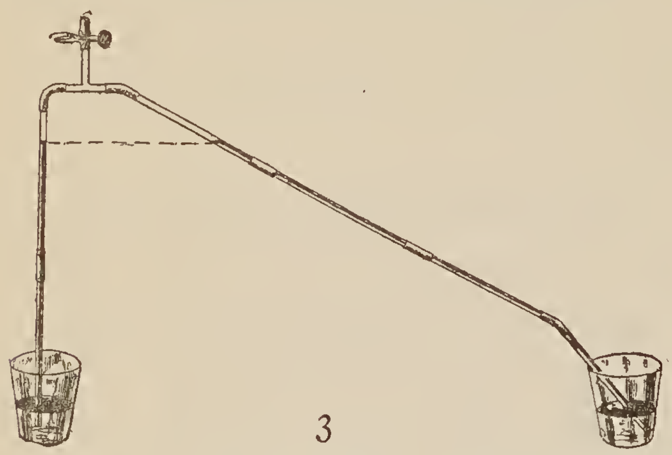

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Fig. 134.—The Height is independent of the Length and Slant of the Tube

EXPERIMENT No. 49

To show that the height to which the atmosphere will lift water in a tube is independent of the size or shape of the tube and of the water surface outside the tube.

Make the experiments (1), (2), (3) and (4) Fig. 135. Is the height of the water always the same in the two tubes?

Make experiments of your own.

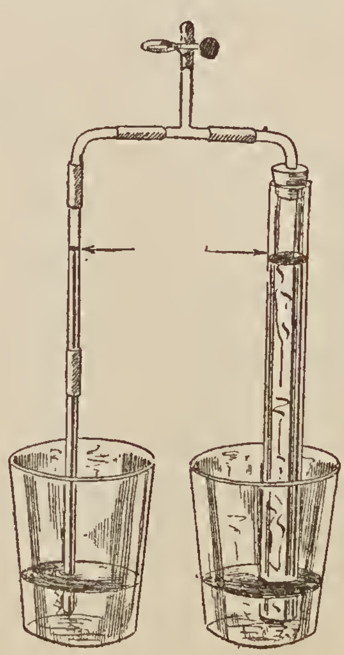

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Fig. 135

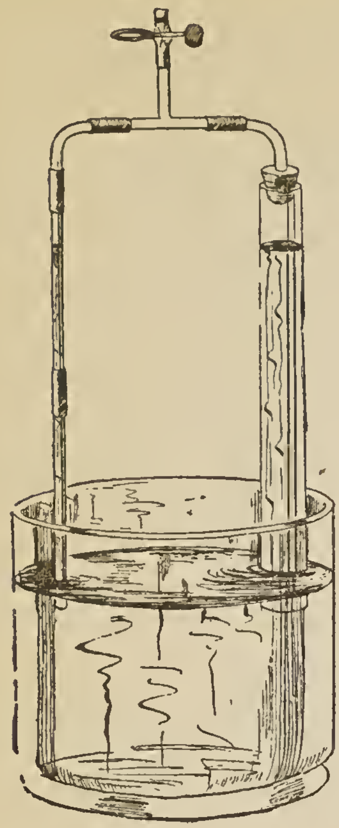

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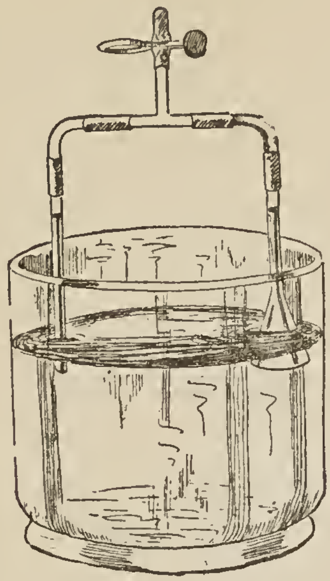
Fig. 135.—The Height is independent of the size or shape of the Tube and of the Water Surface outside the Tube



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EXPERIMENT No. 50

To show that the atmosphere lifts heavy salt water to a less height, and light gasoline to a greater height, than it lifts fresh water.

Make the experiments illustrated in Fig. 136.

EXPERIMENT No. 51

To show that the atmosphere will lift weights.

Make the experiments illustrated in Fig. 137.

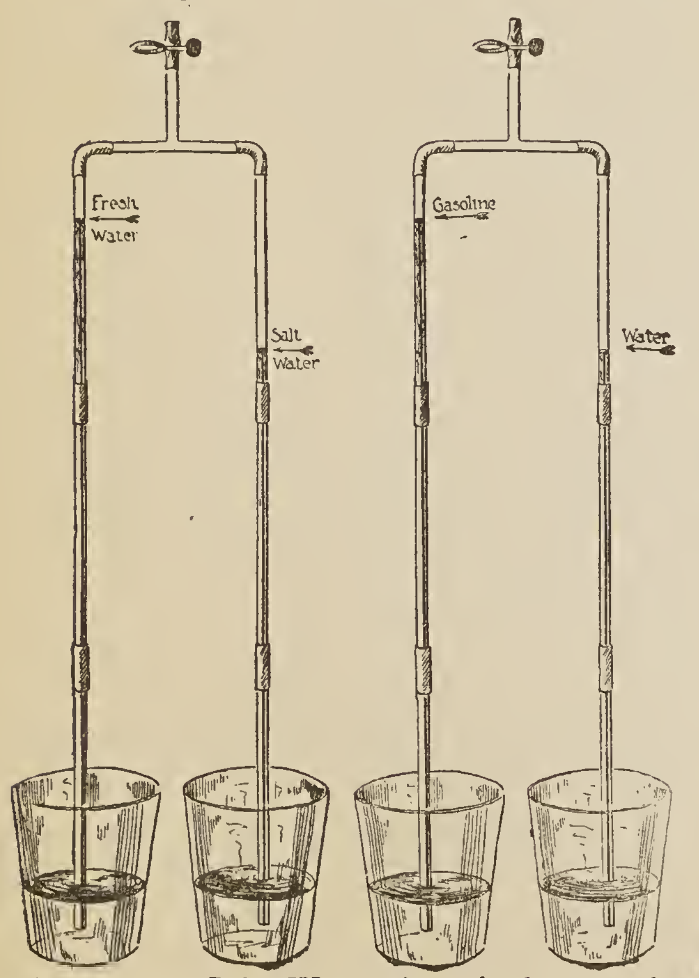

Fig. 136.—Salt Water is raised to a less height than Fresh Water, and Gasoline to a greater height.

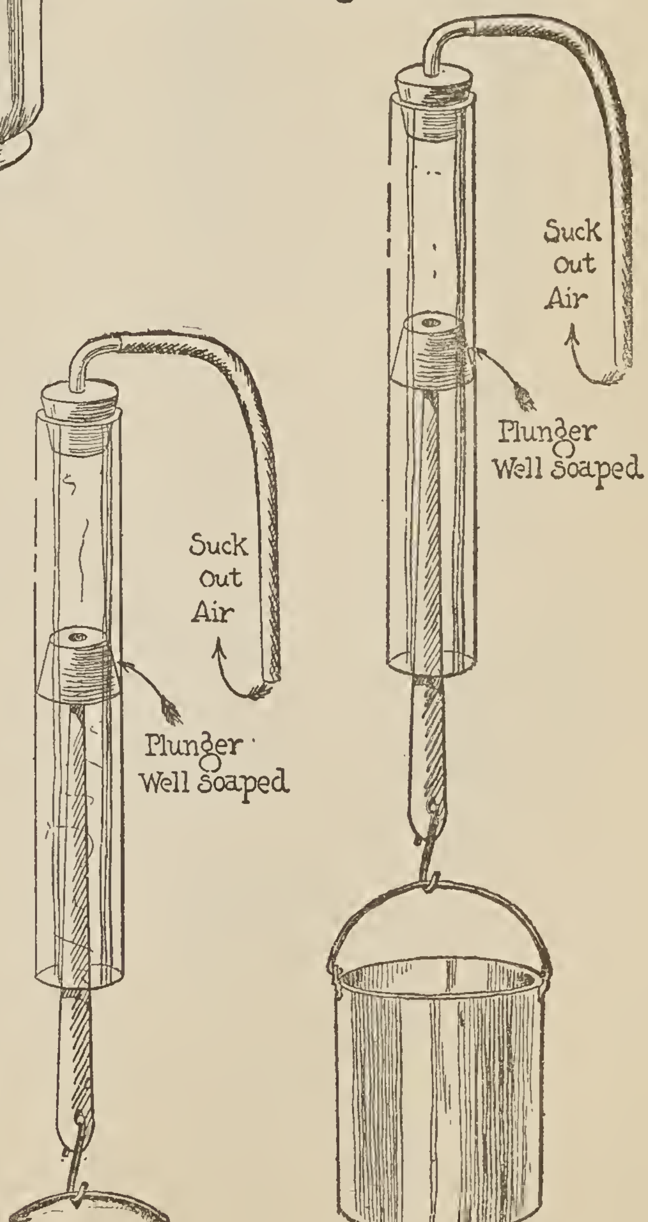

Fig. 137.—Showing that the Atmosphere will lift weight.

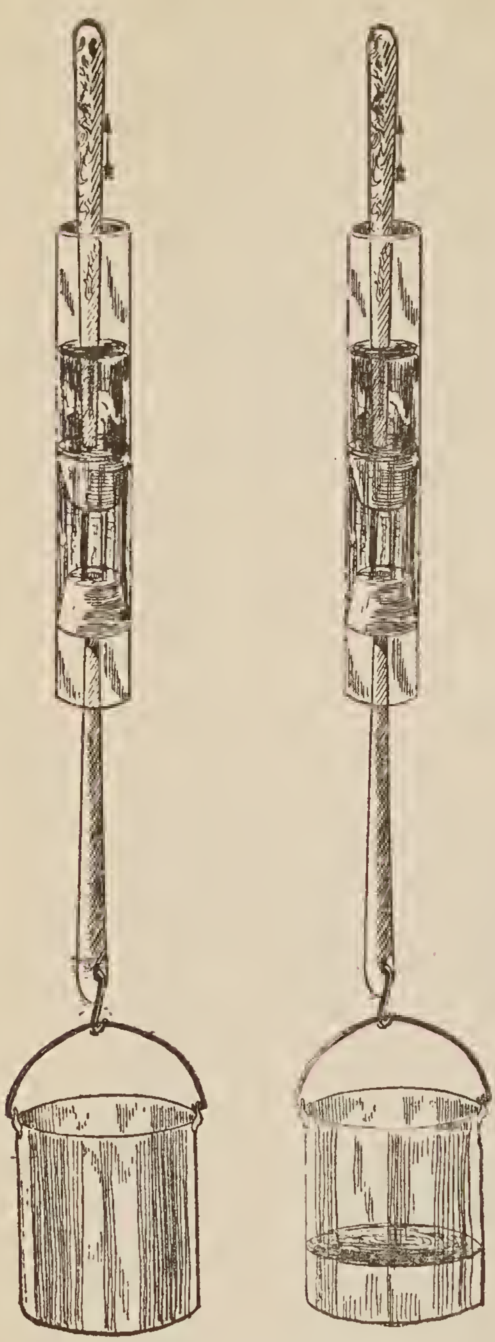

Fig. 138.—Showing that the Atmosphere will lift 15 lbs. per sq. in. but no more.

EXPERIMENT No. 52

To show that the atmosphere will lift 15 lbs. per sq. in. but no more.

The plungers have an area of 3/10 sq. in. If then, the atmosphere will lift 15 lbs. on 1 sq. in., it will lift 3/10 x 15 = 4½ lbs. on 3/10 sq. in.

Soap the plungers, have water between them but no air, pour an inch of water above the upper plunger to make it air-tight, attach a pail weighing less than 4½ lbs. to the lower plunger, Fig. 138 and raise the upper plunger. Does the atmosphere lift the lower plunger and weight?

Add water to the pail until the total weight is 4½ lbs. and raise the upper plunger. Do you find that the atmosphere does not lift the lower plunger? It does not do so because the atmospheric pressure on 3/10 sq. in. cannot lift 4½ lbs. and **also overcome the friction.**

Hold the upper plunger and lift the tube. Does the atmosphere now lift 4½ lbs. weight? It does so because the friction helps it in this case.

Repeat with the water and pail weighing 6 lbs. Do you find that the atmospheric pressure on 3/10 sq. in. will not lift 6 lbs. even with the help of the friction.

You have shown here roughly that the atmospheric pressure on 3/10 sq. in. will lift 4½ lbs. but no more. This shows that the atmospheric pressure on 1 sq. in. will lift 4.5 x 10/3 = 15 lbs. but no more.

Make your own experiments.

AIR-LIFT PUMPS

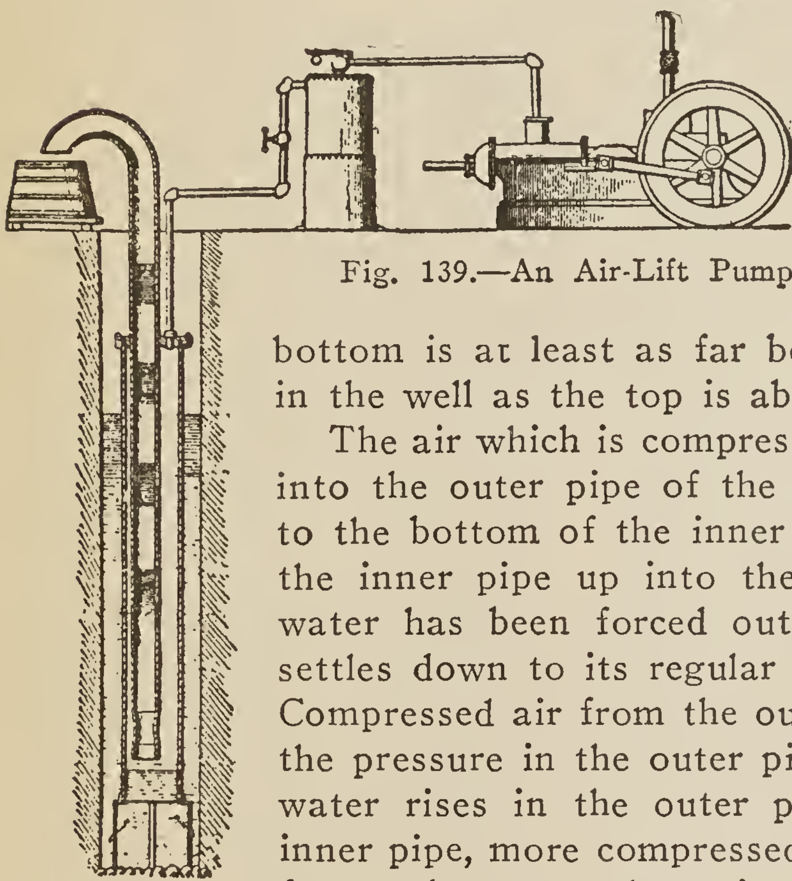

Fig. 139.—An Air-Lift Pump

The air-lift pump, Fig. 139, is operated by compressed air. It consists of two pipes one inside the other, both open at the bottom and without valves. The pump is at least half-submerged, that is, the bottom is at least as far below the surface of the water in the well as the top is above it.

The air which is compressed in the storage tank passes into the outer pipe of the pump, forces the water down to the bottom of the inner pipe, and forces the water in the inner pipe up into the tank. After the first lot of water has been forced out of the inner pipe the pump settles down to its regular operation which is as follows. Compressed air from the outer pipe enters the inner pipe, the pressure in the outer pipe is thereby lowered and the water rises in the outer pipe above the bottom of the inner pipe, more compressed air comes from the tank and forces the water down in the outer pipe but up in the inner pipe. This operation takes place over and over again rapidly, and alternate layers of air and water are forced up the inner pipe as shown in Fig. 139. The water thus flows from the inner pipe into the tank in spurts as you will show in your next experiment.

Another form of air-lift pump is illustrated in Fig. 140. Here the air enters through the inner pipe and the mixture of water and air is

forced out through the outer pipe. The water comes out as a continuous heavy spray because the air is mixed with the water in bubbles rather than in layers.

These are called air-lift pumps but the water is not raised by the air pressure. It is raised by the weight of the water in the well outside the pump, because the water rising in the pump is really a mixture of air and water and is lighter than a water column of the same height.

You can illustrate this by means of experiments shown in Fig. 141. In (1) both sides of the U tube are filled with water and you know from your experiments that the water will be at the same level in both sides. In (II) one side is filled with kerosene oil which is only 8/10 as heavy as water, and you know that a column of water 8 in. high will support a column of oil 10 in high. Similarly in (III) a depth of water of 8 inches will support a column of oil 10 inches high. If now the oil in (III) were replaced by a mixture of air ond water which was only 1/2 as heavy as water, you can see that the 8 inch depth of water would support a column of the mixture 16 inches high, and so on.

The bottom of the air-lift pump is always placed at least as far below the sur-

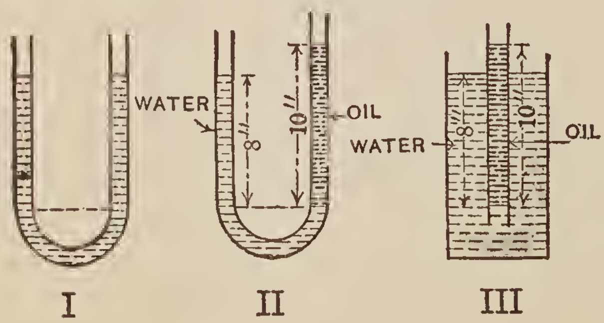

Fig. 141.—A Column of Water supports a longer column of a Light Oil. *Courtesy of the MacMillan Co.*

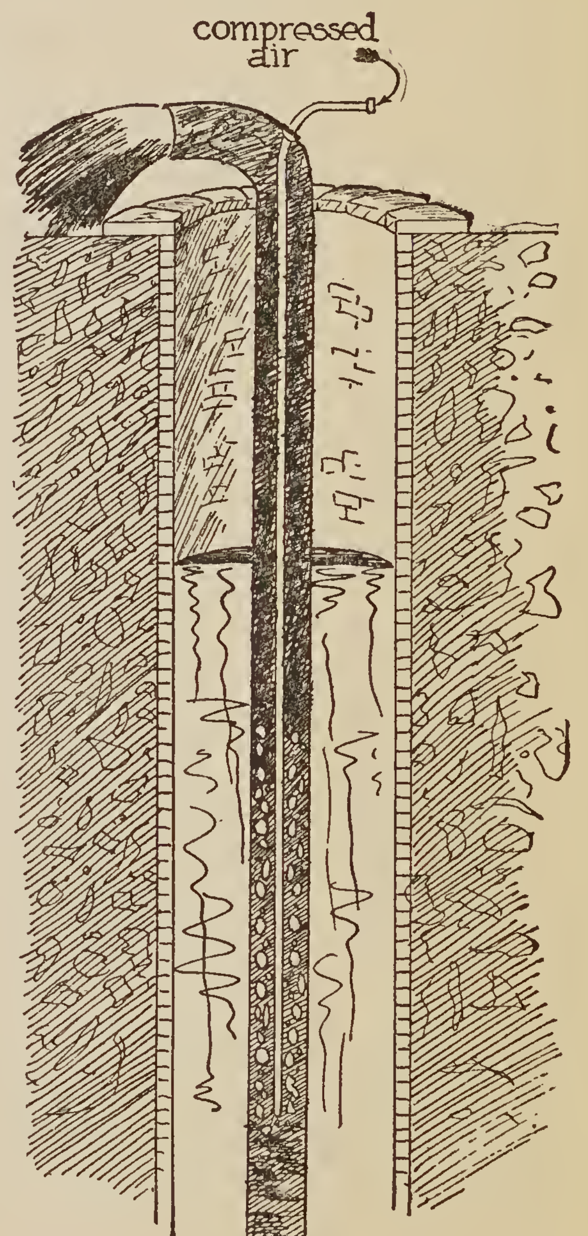

Fig. 140.—Another type of Air-Lift Pump

face of the water as the top is above, and the water outside the pump lifts the lighter mixture of air and water to the top. You will illustrate this in the next experiment.

EXPERIMENT No. 53

To make and operate two air-lift pumps.

Make an air-lift pump. (1) Fig. 142. Use a quart sealer to represent the well, fill it to the top with water, and insert the air-lift pump until it is half submerged, that is, until the water in the sealer is at a point half way between the bottom of the wide tube and the top of the elbow of the discharge pipe.

Force air in through the hose and observe what takes place near the bottom of the pump.

Do you observe that the water level in the pump moves alternately down below the end of the discharge pipe and then up above it, and that alternately water and air are forced up the discharge pipe?

Do you observe further that when you force air in at just the right rate the pump works steadily and the water comes up the discharge pipe in

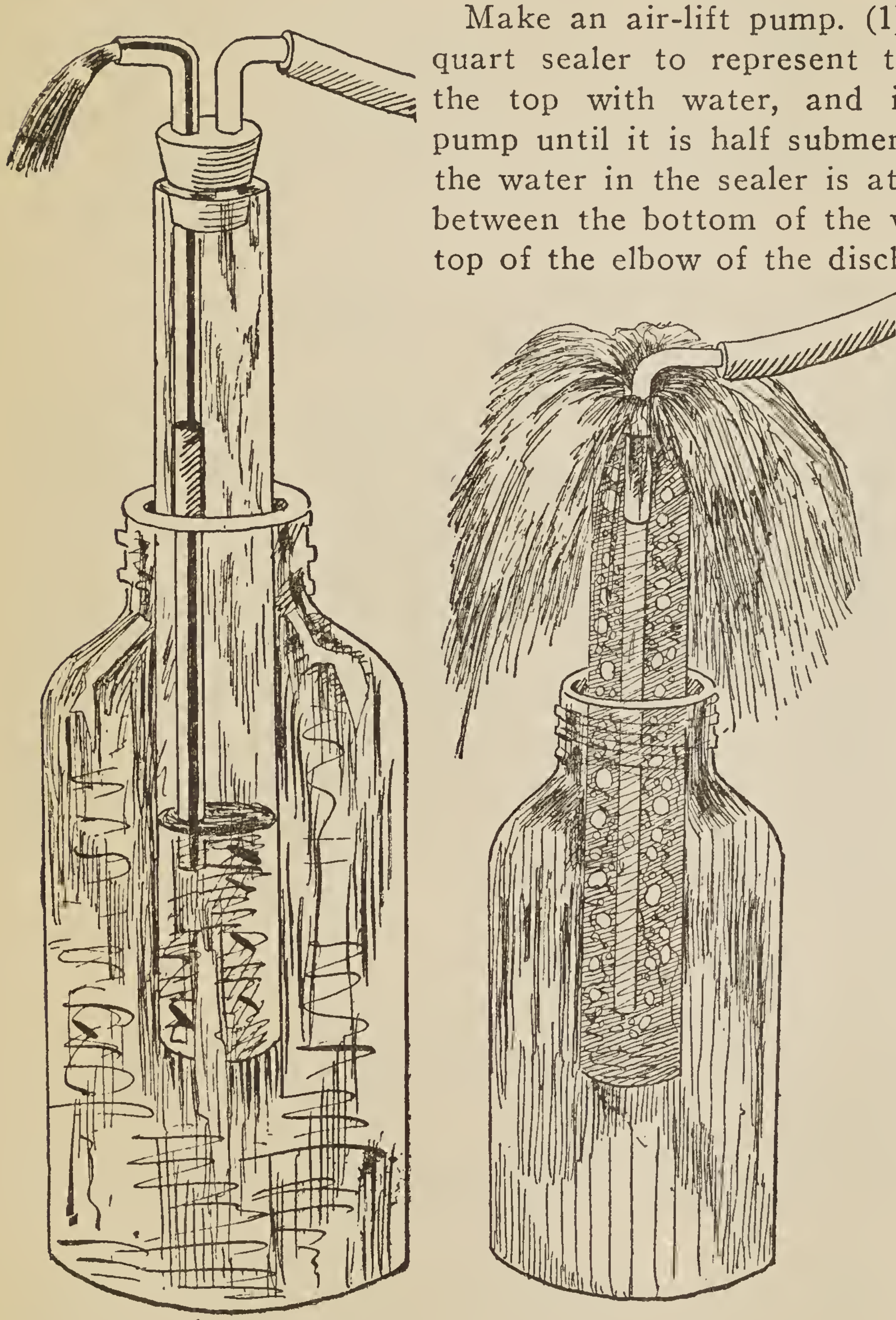

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Fig. 142.—Illustrating the working of two different Air-Lift Pumps.

spurts at regular intervals.

In the other type of air-lift pump the compressed air passes down the inside pipe and the mixed air and water move up the other pipe.

Make a pump of this kind, (2) Fig. 142 and blow air in through the inside pipe.

Do you find that air and water are forced up over the top of the outside pipe?

Repeat the experiment with the pump deeper in the water.

Do you find that it works better the deeper it is in the water?

LAWS WHICH APPLY TO GASES

PASCAL'S LAW

In the remaining pages of this book you will study three laws which apply to gases and you will illustrate many practical applications of these laws. They are Pascal's law, Archimedes' law, and Boyle's law. You will begin with Pascal's law.

You learned on pages 49, 50 and 51, Pascal's law which states one property of liquids; namely, pressure exerted on a liquid is transmitted by the liquid equally and undiminished in all directions. This law also states a property of gases as follows: **pressure applied to a gas is transmitted by the gas equally and undiminished in all directions.**

You are very familiar with one application of this law, namely in the pneumatic tire. The air in a bicycle or automobile tire exerts pressure outward equally at every part of the tire.

EXPERIMENT No. 54

To illustrate Pascal's law as it applies to gases.

Shove the plunger in (1) Fig. 143, down, and feel the air at the nozzles. Are the pressures equal?

Blow a soap bubble (2). Is it a perfect sphere? This shows that the air exerts pressure equally in all directions against the inside of the bubble.

Make a three legged siphon filled with air (3), place two legs in tumblers of water, place the third leg in the wide tube partly filled with water, and raise and lower the wide tube.

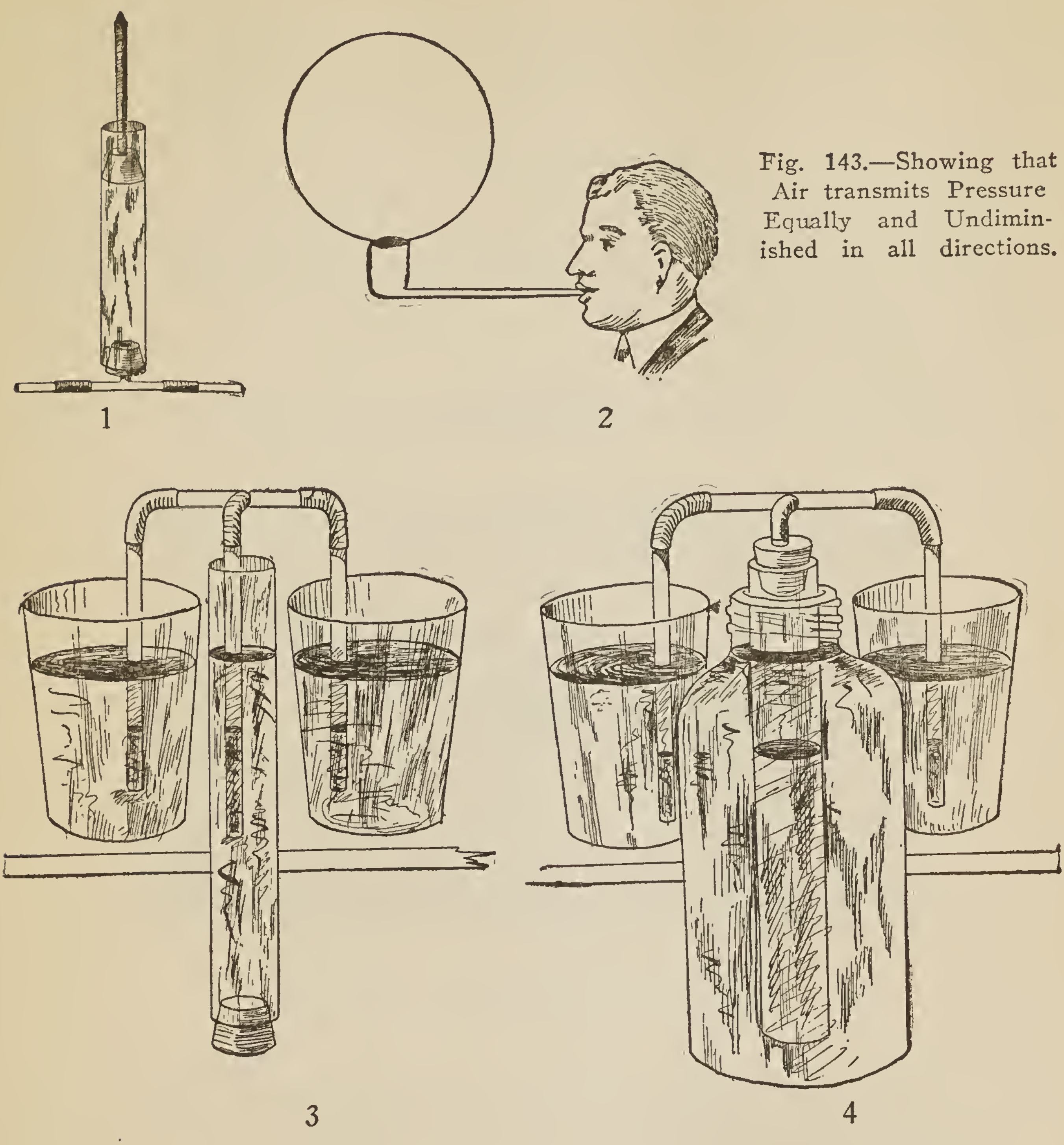


Fig. 143.—Showing that Air transmits Pressure Equally and Undiminished in all directions.

The water in the wide tube exerts pressure on the air in the third leg. Is this pressure exerted **equally** and **undiminished** by the air, that is, is the water level in the three legs always at the same distance below the water outside?

Repeat this with the apparatus (4). Is the result the same?

You have here proved Pascal's law, namely that a gas transmits pressure equally and undiminished in all directions.

BALLOONS AND THE BUOYANT FORCE OF AIR

The Law of Archimedes applied to Gases

Balloons float in air and this fact is due to a property of air which is expressed by the law of Archimedes.

You have already made experiments on this law with liquids and you have shown that **the buoyant force of a liquid on a body is equal to the weight of the liquid displaced by the body.** This is the **law of Archimedes** as it applies to liquids.

The law of Archimedes in regard to gases is: **the buoyant force of a gas on a body is equal to the weight of the gas displaced by the body.**

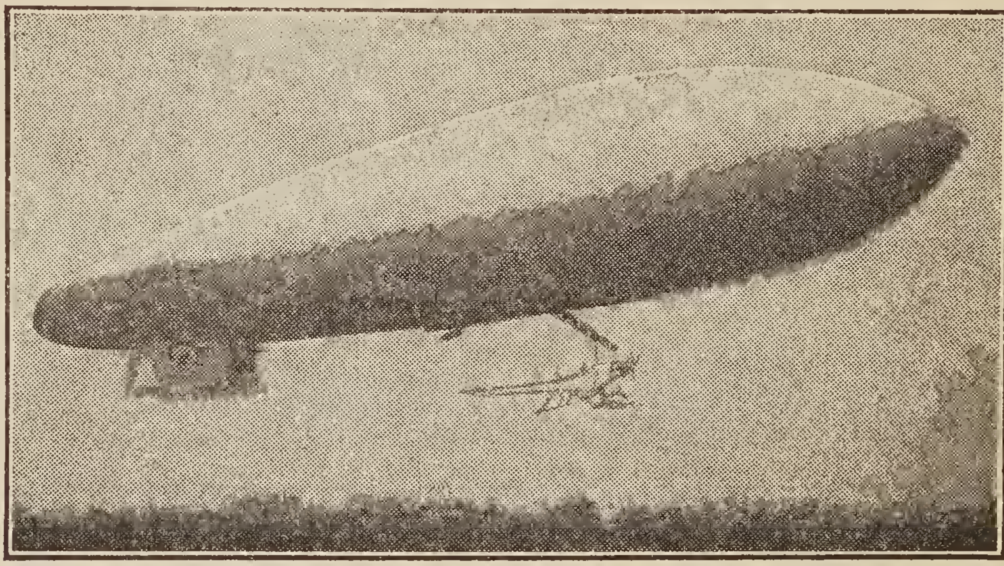


Fig. 144.—The Buoyant Force on the Balloon is Equal to the Weight of Air displaced by the Balloon
Courtesy of "The Scientific American"

How the Total Lift of a Balloon is Calculated

The weight of air is about 1¼ ounces per cubic foot at ordinary temperatures and at the surface of the earth. If then a balloon displaces 1,000,000 cubic feet of air, its total lift or buoyancy is 5/4 x 1,000,000 = 1,250,000 ounces = 1,250,000/16 lbs. = 78,125 lbs. and so on. The **useful load** a balloon can lift is its total lift minus the weight of the envelope, of the gas in the envelope, of the cars, of the engines, and of the fuel.

In Fig. 145 we show the relative strengths in dirigible balloons of Germany, France and Great Britain at the beginning of the war. Britain

and France built many dirigibles during the war and one of the latest built by Britain displaces 1,600,000 cubic feet of air. Its total lift therefore is 1,600,000/16 x 5/4 = 125,000 lbs.

The balloon is filled with hydrogen which weighs about 1/14 as much as air, and therefore 1/14 of the total lift is used up in lifting the hydrogen gas. The weight of the hydrogen is 125,000/14 = 8928 lbs.

Fig. 145.—Comparative Zeppelin Strength of Germany, France Great Britain at the Outbreak of the Great World War.

On the left, thirteen German ships in commission and four (in white) building.
On the right, above, one French ship built and two building.
On the right, below, two British ships building.
Courtesy of The Scientific American

Hydrogen gas has been used in balloons because it is the lightest gas known. It has one great drawback, however, in that it burns very readily. There is another gas called **helium** which is twice as heavy as hydrogen but which has the great advantage that it does not burn.

Before the war helium was very expensive but during the war it was found that the helium which occurs in some of the natural gases of the United States could be separated at a reasonable cost. It is expected that the dirigibles of the future will be filled with helium, and since it does not burn, it will be possible to put the engines in a room inside the balloon as shown in Fig. 146.

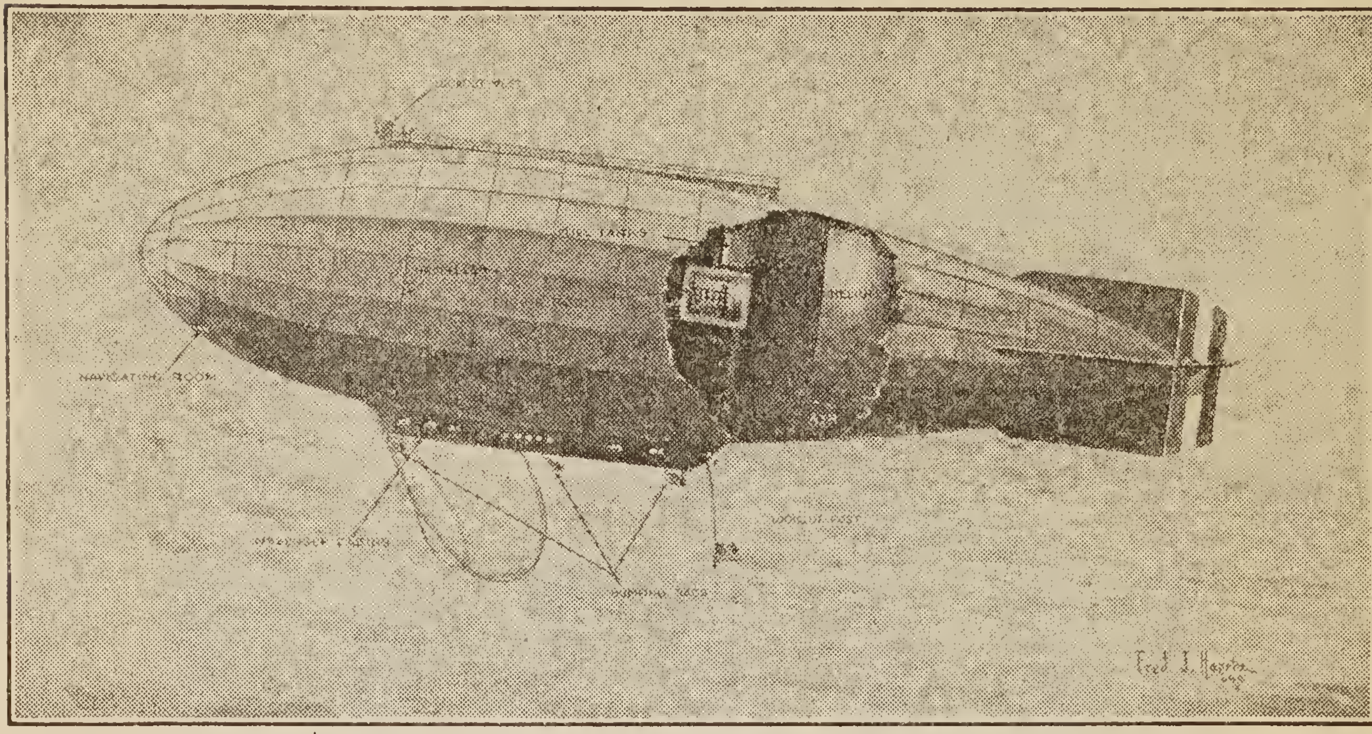


Fig. 146.—Conception of the Passenger-Carrying Dirigible of the Near Future making use of Helium Gas
Courtesy of the Scientific American

Although helium is twice as heavy as hydrogen its lifting power is only 1/13 less because the lift of a balloon depends primarily on the weight of air displaced. You can show this as follows:

If a balloon displaces 140,000 lbs. of air and it is filled with hydrogen, it holds 140,000/14 = 10,000 lbs. of hydrogen, since hydrogen weighs 1/14 as much as air.

If the balloon is filled with helium it holds 140,000/7 = 20,000 lbs. of helium, since helium weighs 1/7 as much as air.

The lift minus the weight of hydrogen = 140,000 — 10,000 = 130,000 lbs.

The lift minus the weight of helium = 140,000 — 20,000 = 120,000 lbs.

That is, the lift with helium is only 1/13 less.

EXPERIMENT No. 55

To illustrate the buoyant force of air.

Blow a soap bubble with illuminating gas (1) Fig. 147.

Does the bubble rise?

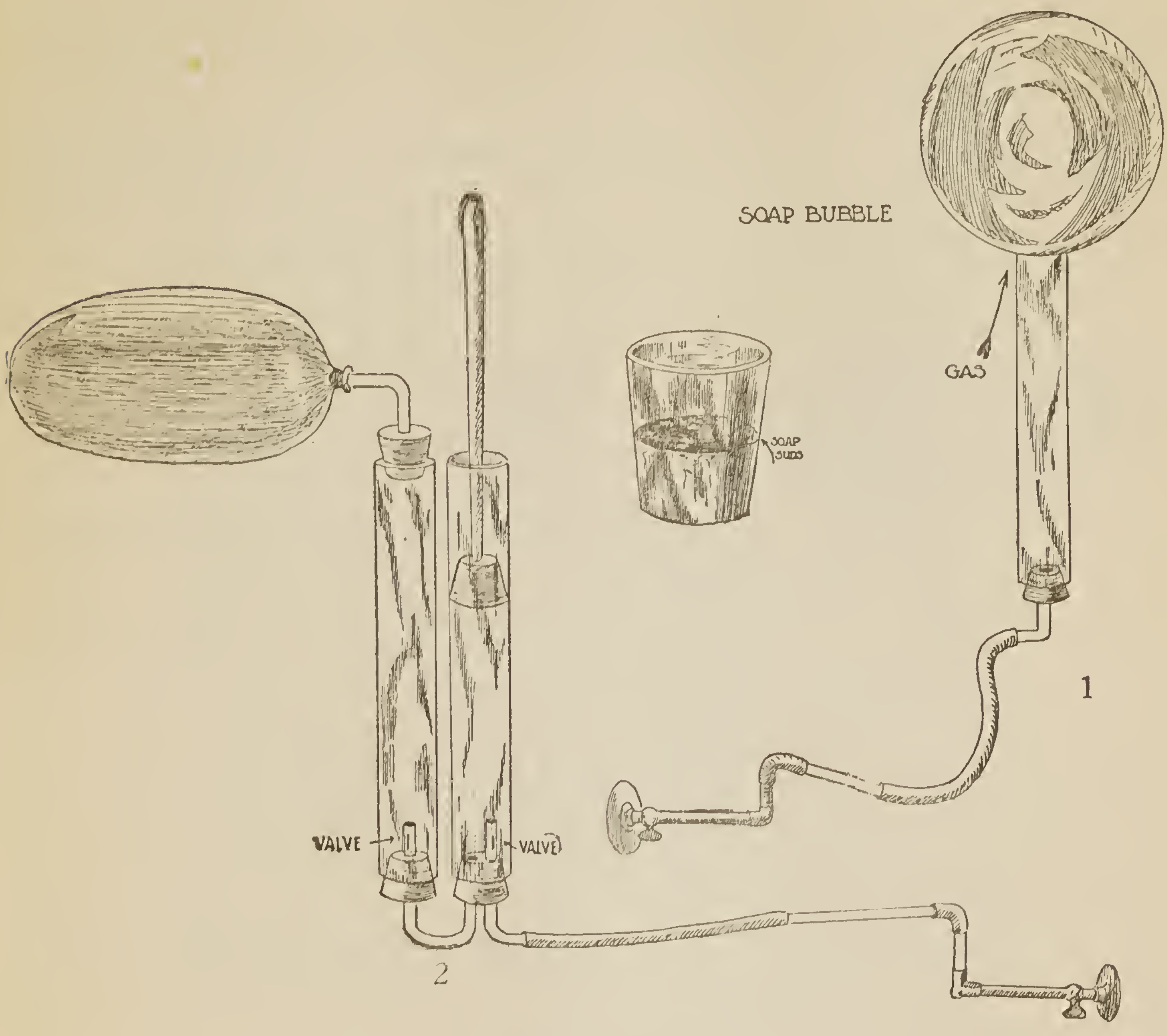


Fig. 147.—Filling a Bubble and a Balloon with Illuminating Gas

Blow up a balloon with illuminating gas by means of the force pump (2) Fig. 147. Does the balloon rise?

The bubble and balloon rise because they displace a greater weight of air than their own weight plus the weight of the gas in them.

EXPERIMENT No. 56

To illustrate the buoyant force of air by means of a balloon filled with hydrogen.

If the metal zinc is placed in an acid, the metal is dissolved by the acid and hydrogen gas is produced. You can make hydrogen gas and fill the large balloon with it as follows.

Purchase at a drug store 2 ounces of strong hydrochloric acid (also called muriatic acid) which should cost about 5 or 10 cents; also purchase at an electrical shop a zinc rod for a Leclanché battery, which will also cost about 5 or 10 cents, or purchase two zinc strips.

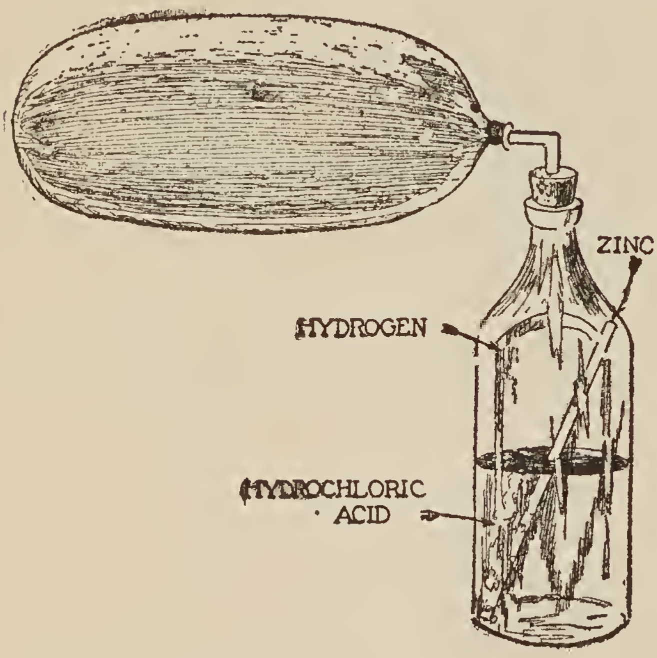


Fig. 148.—Filling a Balloon with Hydrogen

Pour the acid into the bottle and add an equal volume of water. This dilutes the acid and slows up the production of the hydrogen. If the hydrogen is produced too fast it will bubble acid up into the balloon.

Now to make hydrogen and to fill the balloon, proceed as follows: Arrange the bottle as shown in Fig. 148 and attach the large balloon to the elbow by means of a short piece (about 1½ in.) of a **stretched rubber band.** When you have done this place the zinc rod or zinc strips gently in the bottle, insert the stopper at once, and allow the hydrogen to fill the balloon. It will take about 5 minutes to fill the large balloon completely.

When the balloon floats well in the air, slip it off the elbow **with its stretched rubber band.** The band will contract and close the balloon.

Now release the balloon. Do you find that it floats up to the ceiling? **Precautions.** Be very careful not to get any of the acid on your hands or clothes. It will burn very bad holes if it does.

When you are through empty out the liquid left in the bottle, as it is of no further use, and rinse the bottle and rod very thoroughly with water.

You must not use the zinc in small pieces because it produces the hydrogen too fast and makes the acid bubble up into the balloon. Use the zinc in the shape of a rod or strips.

EXPERIMENT No. 57

To shoot down a balloon.

We show in Fig. 149 three views of a balloon shot down by means of incendiary bullets. These bullets set the hydrogen on fire, the envelope burns, and the car and machinery fall to the ground.

Fig. 149.—Three Phases of a Successful Attack on an Obseravtion Balloon

1 — Immediately after the "hit" has been scored. Note the aeroplane and balloon.
2 — Balloon enveloped in flames is fast reduced to a shapeless mass.
3 — Wreckage of the observation balloon falling to earth, with a smoke trail in its wake.

Courtesy of the Scientific American

A toy balloon filled with hydrogen as in the last experiment floats up to the ceiling. It will come down by itself in a few hours because the hydrogen gradually passes out through the rubber.

If you are in a hurry to get the balloon down, and if you have an air riflle, you can shoot a hole through the balloon: the hydrogen will then escape and the balloon will fall at once. This method, however, spoils the balloon.

Fig. 150.—Shooting Down a Small Balloon

You can shoot the balloon down with a syringe without destroying it as shown in Fig. 150. The water on the balloon will make its weight greater than the buoyancy of the air displaced by the balloon and this will bring it down.

If you let the water evaporate, the balloon will rise again because it again becomes lighter than the air it displaces. You can then shoot it down again with water.

EXPERIMENT No. 58

To illustrate the buoyant force of a gas heavier than air by means of a soap bubble filled with air.

Purchase at a drug store one ounce of ether and pour it into an empty 12 qt. pail, cover the pail with a newspaper and allow it to stand for about 10 minutes.

The ether will evaporate and produce ether gas. This being heavier than air will remain in the bottom of the pail and force the lighter air out at the top.

Now dip the end of the wide tube in the soap suds and shake off the excess soapy water. Blow a large bubble and detach it about 6 in. above the bottom of the pail.

Do you find that the soap bubble filled with air floats on the heavy ether gas?

The buoyant force of the ether gas is the weight of this gas displaced by the bubble. This buoyant force is sufficient to support the soap bubble film and the air inside of it.

Fig. 151.—Illustrating the Buoyant Effect of a Heavy Gas.

COMPRESSED AND EXPANDED GASES

BOYLE'S LAW

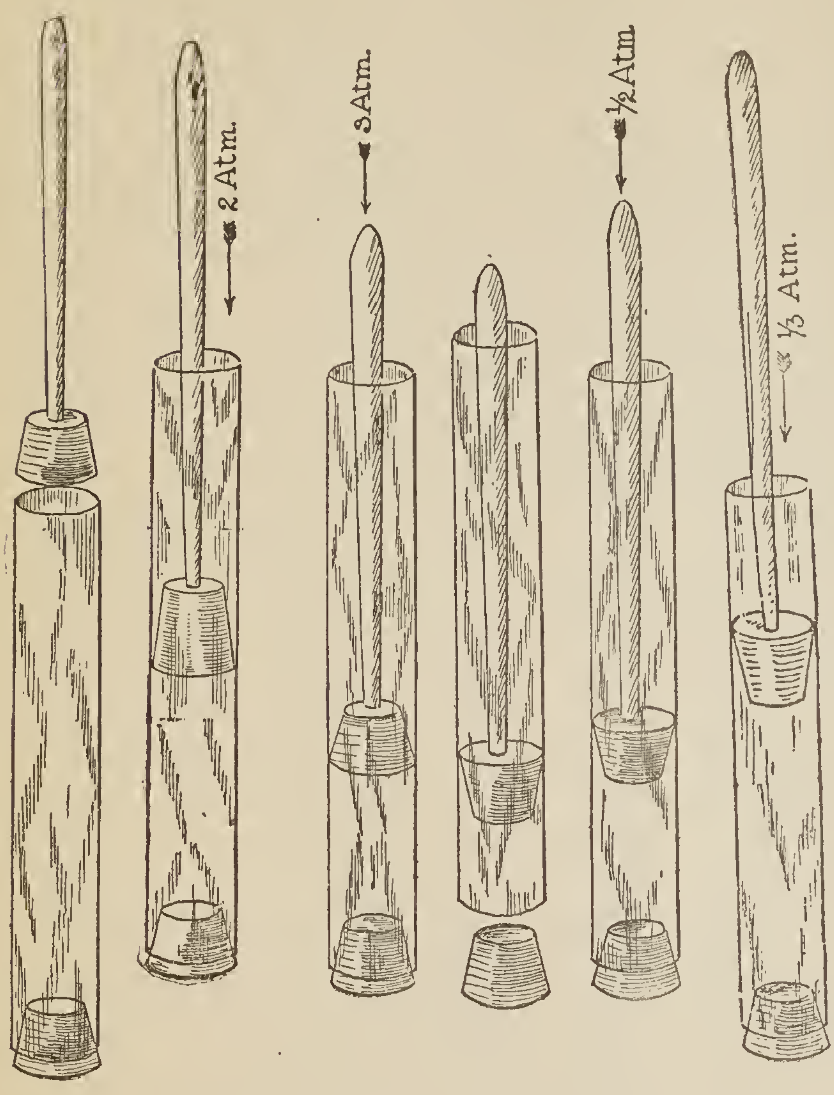


Fig. 152.—The Volume of a Gas Varies Inversely as a Presure on it

You will now illustrate Boyle's law and then make a number of appliances which make use of this law, namely, the air brake, flame thrower, fire extinguisher, air pump, bicycle pump, sand blast, pneumatic paint brush, diving bell, pneumatic caisson, and submarine air supply.

Boyle's law is: **The volume of a gas varies inversely as the pressure on it.** This is illustrated in Fig. 152. In (1) the tube is full of air and the pressure on the air is one atmosphere because the tube is open to the atmosphere. In (2) the pressure on the air is 2 atmospheres and the volume of the air is 1/2 what it was in (1). In (3) the pressure on the air is 3 atmospheres and the volume of the air is 1/3 what is was in (1) and so on.

In (4) the air in the tube below the plunger is under 1 atmosphere pressure because the tube is open to the atmosphere. In (5) the tube is closed, the plunger is raised until the pressure on the air is 1/2 atmosphere and its volume is two times what it was in (4). In (6) the plunger is raised until the pressure on the air in only 1/3 and its volume is three times what it was in (4).

These illustrate Boyle's law.

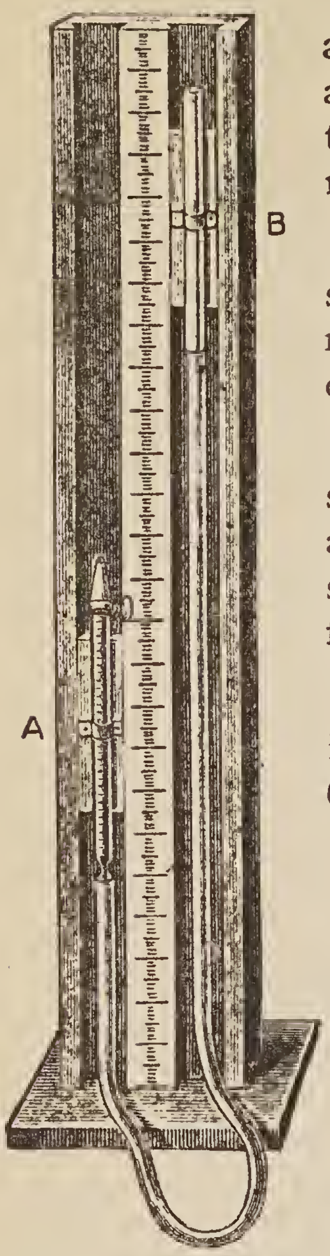


Fig. 153.—Apparatus used to Illustrate Boyle's Law
Courtesy of The MacMillan Co.

Boyle's law is usually illustrated by means of the apparatus shown in Fig. 153. The glass tube A is closed at the top and is partly filled with air, the second glass tube B is open at the top, and the two tubes are connected by a rubber tube filled with mercury.

The mercury surfaces at the beginning are at the same level, (1) Fig. 154, and since the pressure on the mercury surface in B is 1 atmosphere, the pressure on the air in A is also 1 atmosphere.

If now B is raised until its mercury surface is 30 in. above that in A, the air in A is under 2 atmospheres pressure and it is compressed to 1/2 its first volume, (2).

If B is raised until its mercury surface is 60 in. above that in A, the air in A is under 3 atmospheres pressure and it is compressed to 1/3 its first volume (3), and so on.

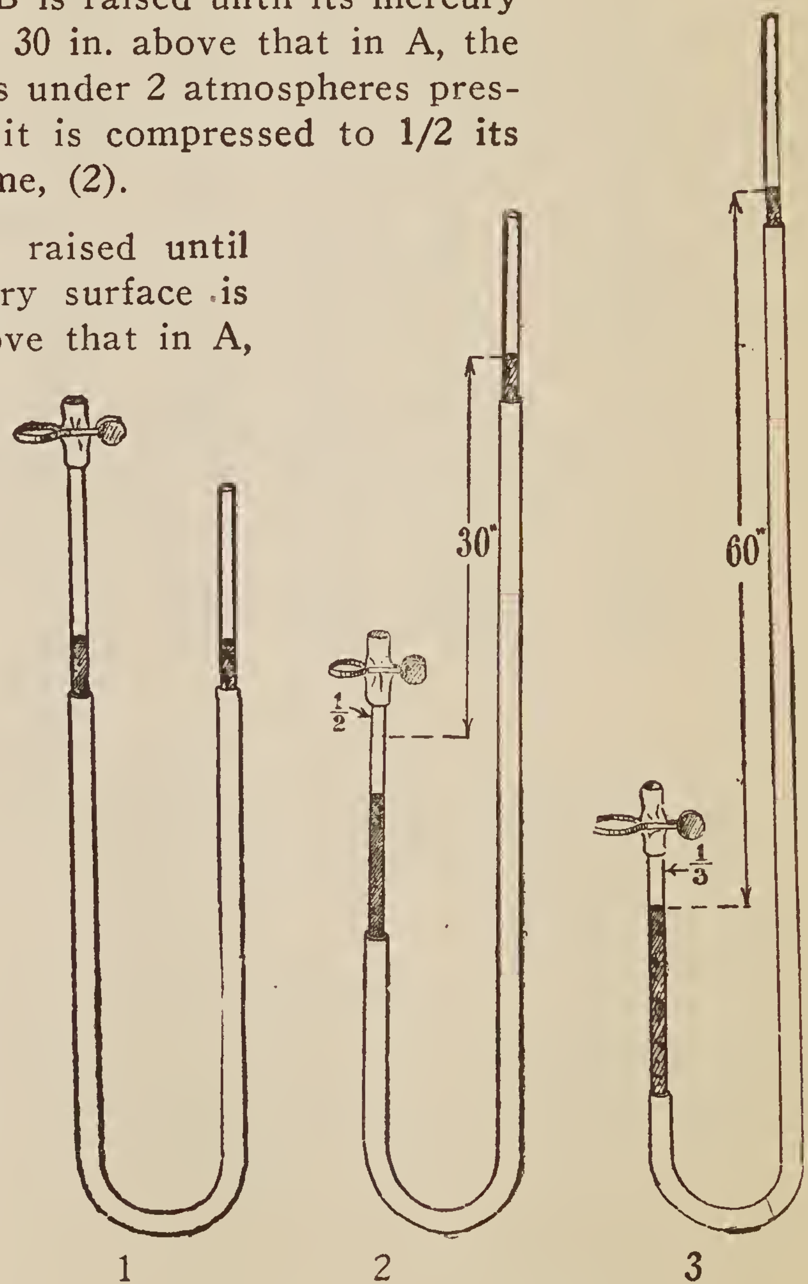
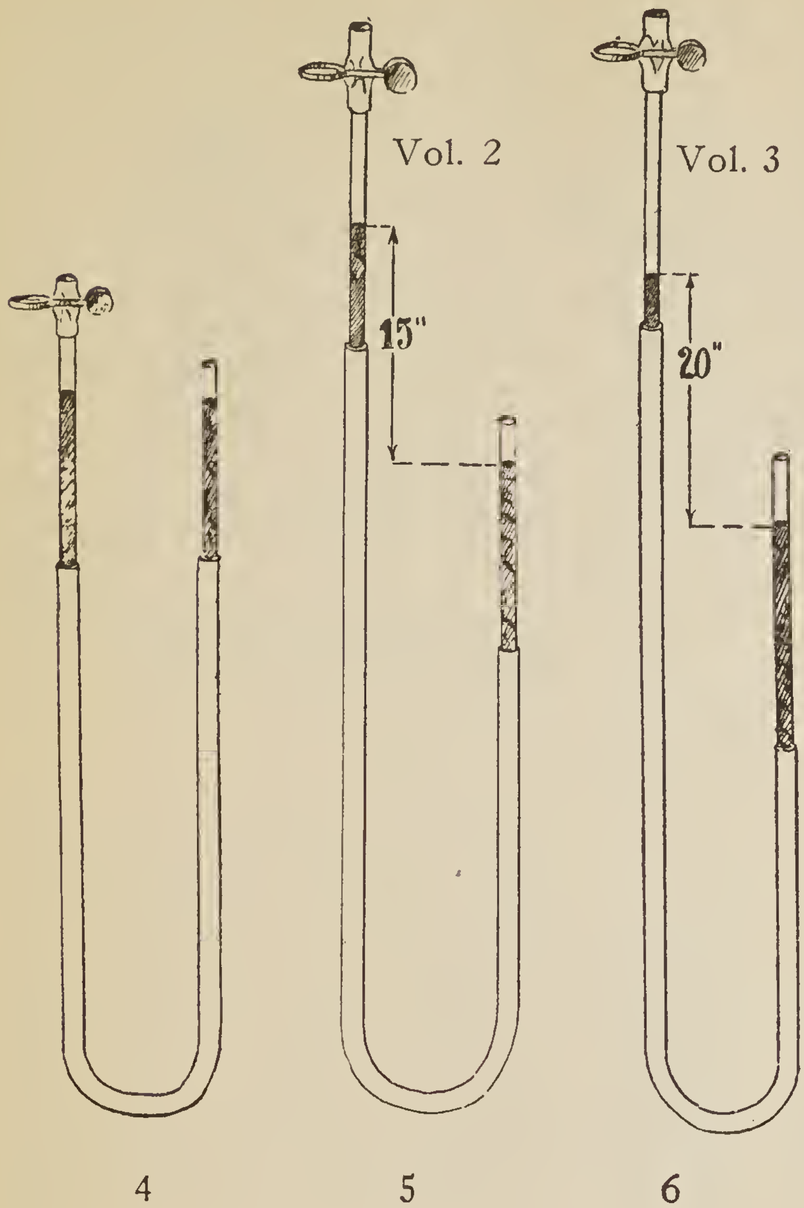


Fig. 154.—Illustrating Boyle's Law

If on the other hand, B is lowered, (5), until its mercury surface is 15 in.



Illustrating Boyle's Law

below that in A, the air in A is under a pressure of only 1/2 atmosphere and it expands until its volume is 2 times its volume in (4).

If B is lowered (6) until its mercury surface is 20 in. below that in A, the air in A is under a pressure of only 1/3 atmosphere and it expands until its volume is 3 times its volume in (4), and so on.

Note: A column of mercury 30 inches high exerts a pressure equal to that of one atmosphere. Similarly 15 in. = 1/2 atmosphere and 10 in. = 1/3 atmosphere.

EXPERIMENT No. 59

To illustrate Boyle's law.

If you have a spring balance you can prove Boyle's law as follows: Use the apparatus (1) Fig. 155 and compress the air to one half its volume as in (2). Is the average pull on the balance 4½ lbs.?

Note: Friction opposes the plunger when it is moving in, but it helps the plunger to remain in. You will find that it takes more than 4½ lbs. to compress the gas, but less than 4½ lbs. to hold it after it is compressed, the average is 4½ lbs.

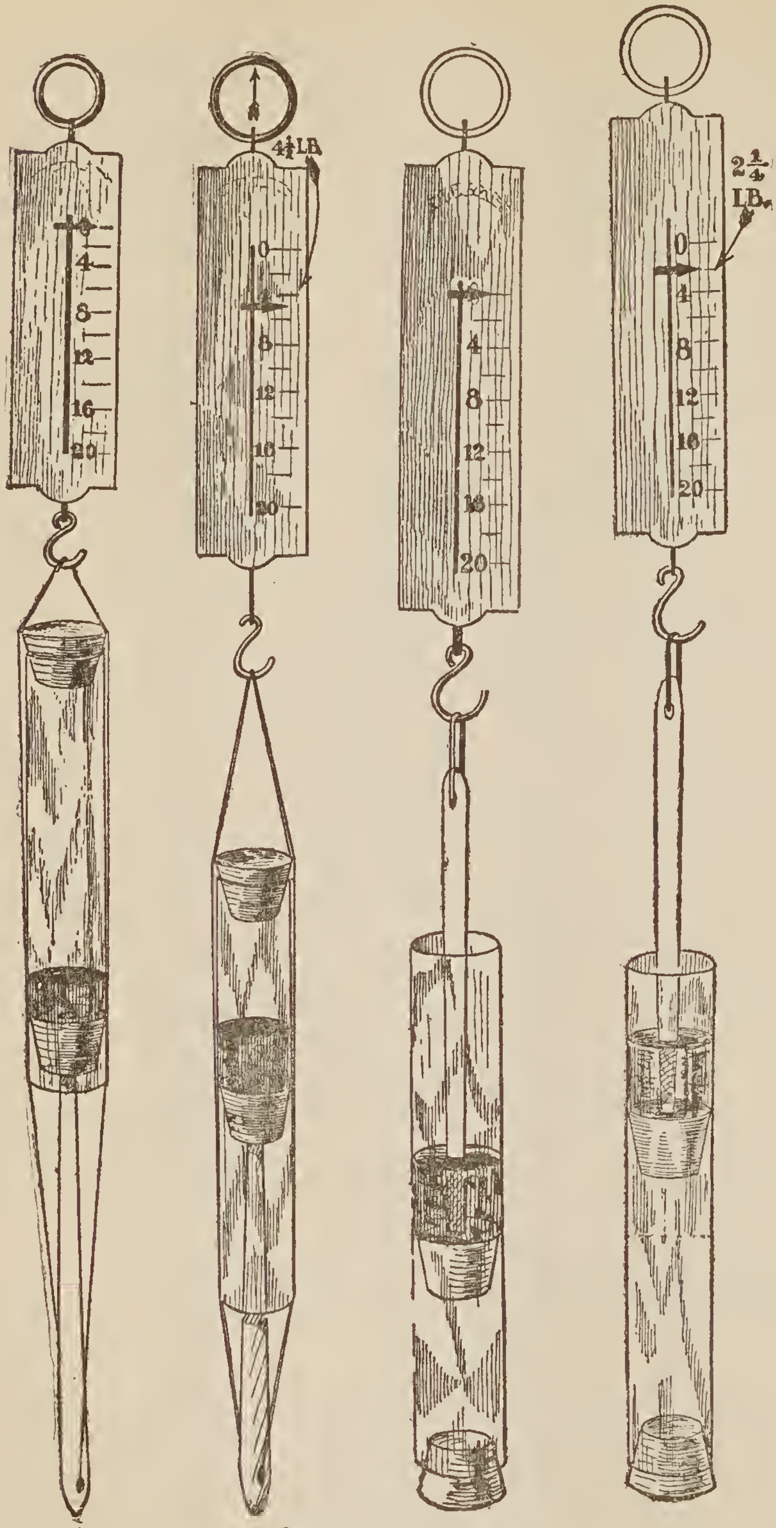


Fig. 155.—Double the Pressure on Air and you Half the Volume. Half the Pressure and you Double the Volume.

The area of the plunger is 3/10 sq. in., therefore the pressure per square inch is 4.5 x 10/3 = 15 lbs. or 1 atmosphere, but the air on the outside exerts a pressure of 1 atmosphere on the plunger, therefore the total pressure the plunger exerts on the air in the tube is 1 + 1 = 2 atmospheres.

You have shown here that when you double the pressure on a gas you compress the gas to one half its first volume.

To show that when you halve the pressure on a gas its volume doubles, use the apparatus (3) Fig. 155.

Start with a distance of 2 inches between the plungers, (3) then pull up the spring balance until the distance is 4 inches, (4). Is the average pull on the balance 2¼ lbs.?

A pull of 2¼ lbs. on 3/10 sq. in. is 2.25 x 10/3 = 7.5 lbs. per sq. in. or ½ atmosphere. Since the pull of the balance is only ½ atmosphere, the air in the tube must be exerting the other ½ atmosphere.

You have shown here that when the pressure on air is halved its volume increases to double what it was at first.

THE AIR BRAKE

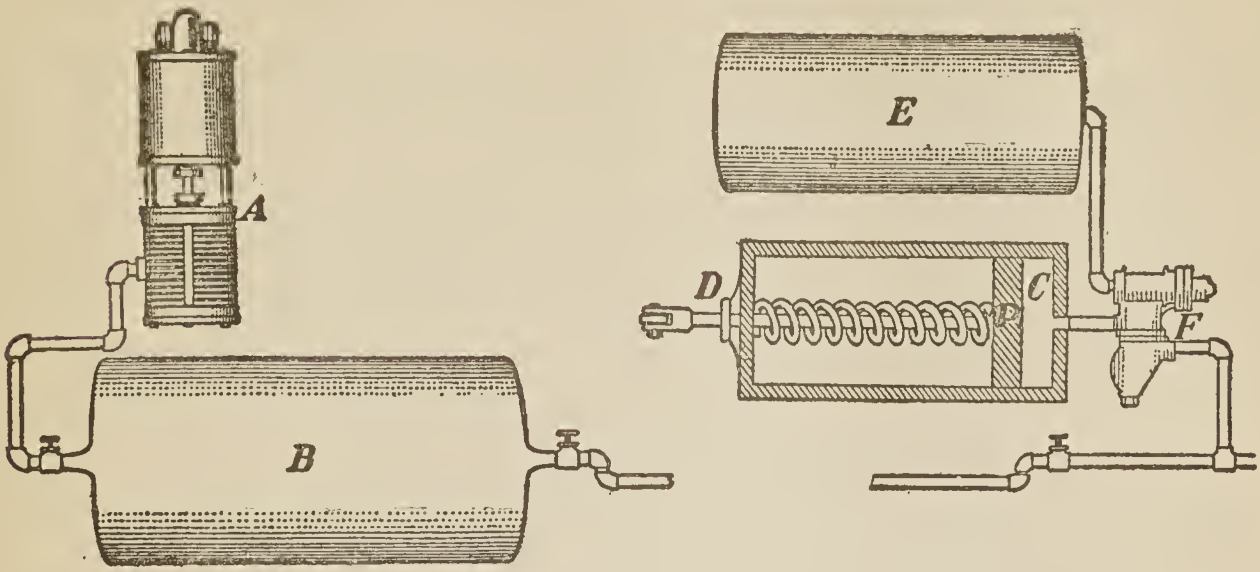


Fig. 156.—Air Brakes for Trains

From the "Ontario High School Physics", By Permission of the Publishers

One of the commonest applications of compressed air is in the air brakes on trains. The air compressor A, on the side of the engine boiler, is operated by steam from the boiler. It compresses air in the large tank B, on the locomotive, and this compressed air is carried through the train pipe under the cars to the air brake under each car. The air brake on each car consists of a triple valve F, an air tank E and a cylinder C containing a piston P. The brake beam is attached to D.

The operation of the air brakes is as follows: Air is pumped into the locomotive tank B until its pressure is about 75 ℔s. per sq. in. This compressed air moves through the train pipe, through the triple valve F, and into the car tanks E.

When the train is running, the pressure in each car tank E is equal to that in the locomotive tank B; but there is no air in the cylinder C and the brakes are "off", because the spring holds the piston P in the position shown.

When the engineer puts "on" the brakes, he turns a lever which closes the valve between B and the train pipe, and which at the same time, lets the air out of the train pipe. When the air pressure in the train pipe

decreases, the triple valve shifts in such a way that compressed air passes from the tank E into the cylinder C; this compressed air drives the piston out with a pressure of 75 lbs. per sq. in. and puts the brakes "on."

When the engineer wishes to take the brakes "off" again, he turns the lever back. This closes the train pipe and at the same time allows air to flow from tank B through the train pipe to the triple valve F. When the pressure in the trian pipe increases, the triple valve shifts back in such a way that it lets air pass from B into E, also it closes the passage from E to C, and lets the air out of C. The spring then forces the plunger in and takes the brakes "off".

It will be noticed that if the train should break in two by the breaking of a coupling, the rubber air hose connection on the train pipe is broken and the air is let out of the train pipe. This automatically sets the brakes on each car and both parts of the train are brought to a standstill.

You will now make and operate an air brake and illustrate the working of the cylinder, triple valve, and air tank.

EXPERIMENT No. 60

To make and operate an air brake and to illustrate the working of the triple valve, cylinder, air tank, and train pipe.

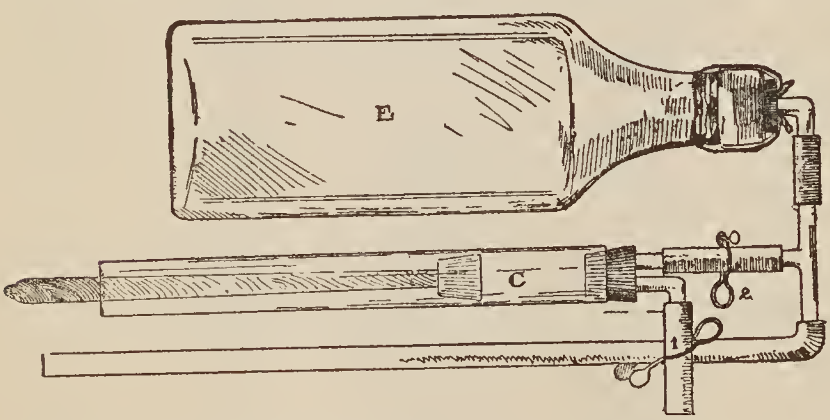


Fig. 157.—Illustrating the Working of the Air Brake

Use the apparatus as shown in Fig. 157, open clip 1, and blow air into the rubber tube.

Your mouth here represents the compressor and air tank on the locomotive, and while you are blowing air into the tank E you are representing the conditions when the train is running and the brakes are "off". You will notice here that when clip 1 is open and 2 is closed the triple valve is admitting air to the tank E, the cylinder C is open, and the brakes are "off". Clips 1 and 2 represent the triple valve.

Now close clip 1 and open clip 2. Do you observe that the compressed air in E forces the piston out? This is exactly what happens when the

engineer puts the brakes "on". You will notice here that when clip 1 is closed and 2 is opened, the triple valve has closed the passage between the cylinder and train pipe, and has opened the pipe between E and the cylinder. This is the condition when the brakes are "on".

If you have a bicycle pump, use it instead of your mouth and pump more air into the tank E. You will then find that the piston is driven out with greater force.

At the next opportunity examine the air brakes under a box car or flat car on a railway siding. Identify the air tank, cylinder, piston rod end, the triple valve, and the train pipe. Notice that the outward movement of the piston rod, moves a lever, and that this lever in turn sets the brakes.

THE FLAME THROWER

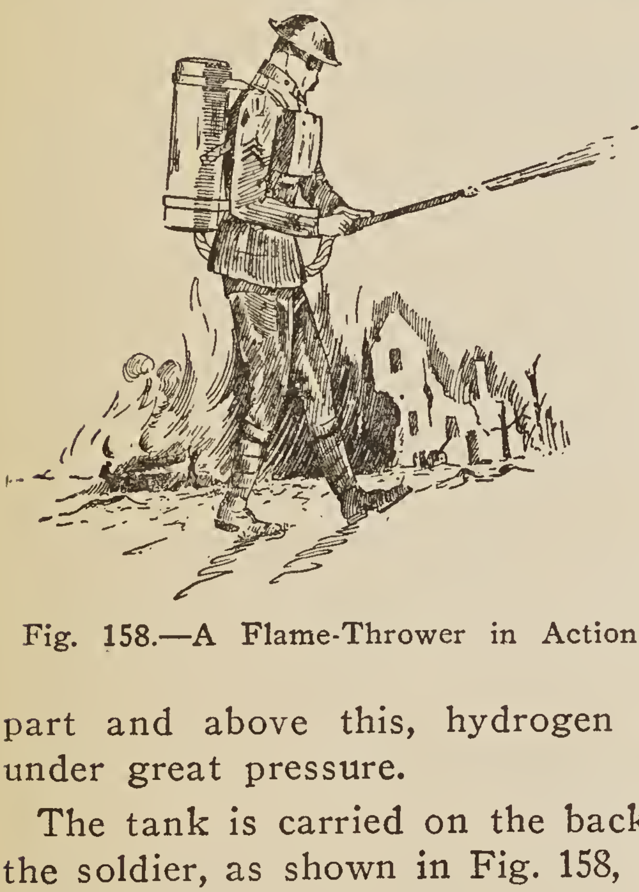


Fig. 158.—A Flame-Thrower in Action

You have read of the flame throwers, which were used during the war. You will illustrate their action in the next experiment.

A flame thrower is a strong metal tank with a pipe and nozzle leading from the bottom. It contains a mixture of inflamable oils in the lower part and above this, hydrogen gas under great pressure.

The tank is carried on the back of the soldier, as shown in Fig. 158, and when the nozzle is opened the compressed hydrogen drives the oil out with great force. The oil is set on fire by a pilot light just beneath the nozzle and the moving stream becomes a stream of flame or liquid fire.

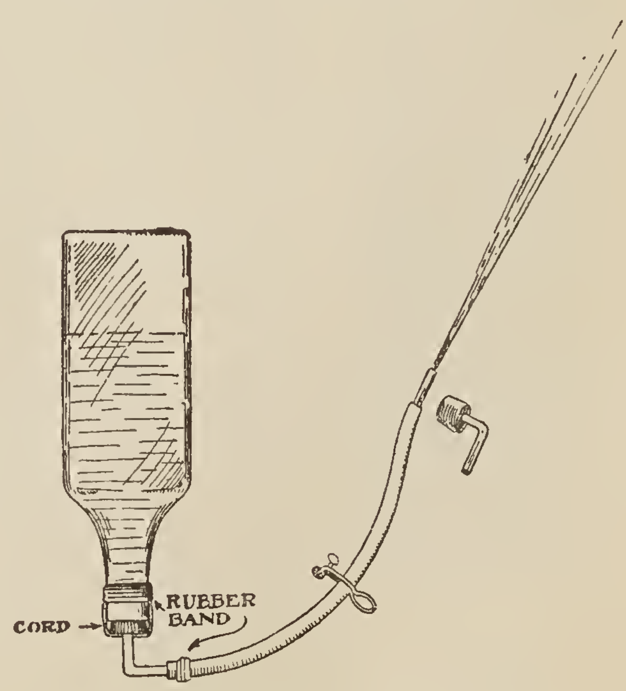


Fig. 159.—Showing how the Compressed Hydrogen drives the Oil out of a Flame Thrower

EXPERIMENT No. 61

To illustrate the action of the flame thrower.

It is dangerous to illustrate the action of a flame thrower with oil and you will use water instead.

Arrange the apparatus as shown in Fig. 159. To load the flame thrower, place a clip on the rubber tube, put a stopper and elbow on the end, insert the stopper into a water faucet, open the faucet gently, open the clip, and allow water to enter the bottle until it is one half full, then close the clip.

The flame thrower is now loaded; the water represents the oil and the compressed air represents the compressed hydrogen.

Now to use the flame thrower; replace the elbow and stopper at the end of the rubber tube by a nozzle, turn the bottle upside down, point the nozzle at the thing you wish to hit, and open the clip.

THE FIRE EXTINGUISHER

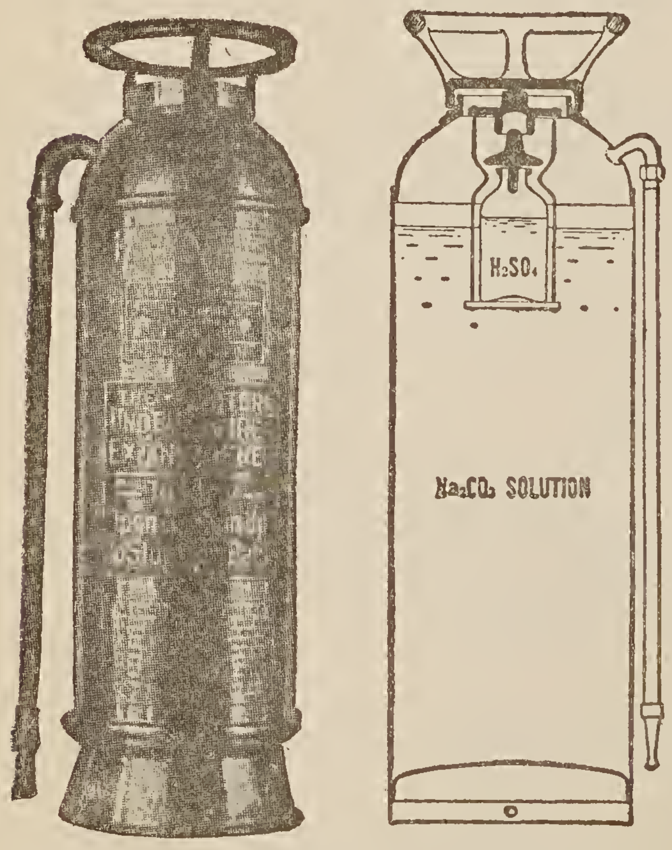


Fig. 160.—Showing the Outside and Inside of a Fire Extinguisher
Courtesy of the MacMillan Co.

The common household fire extinguisher, Fig. 160, is a strong brass cylinder with a short piece of hose attached at the top; this hose and its nozzle are open at all times. The extinguisher is charged as follows: In the bottom there is a solution of 1½ lbs. of sodium carbonate (Na_2CO_3) and 2½ gal. of water, and above this there is an 8 oz. bottle containing 4 ozs. of strong sulphuric acid (H_2SO_4). This bottle is fitted with a loose lead stopper which falls out when the extinguisher is turned upside down.

To use the extinguisher, you carry it **right side up** to the fire, then turn it **upside down** and direct the stream of water and gas upon the fire by means of the short hose. Use all of the water, because once you have turned the extinguisher upside down, the liquids are mixed, and the extinguisher is of no further use until you have re-

charged it. You should do this at once in order to be prepared again for a fire. In recharging you should follow the directions printed on the case.

The action which takes place in the extinguisher is as follows: when you turn it upside down, the sulphuric acid and sodium carbonate react chemically and produce a large quantity of carbon dioxide gas. The volume of carbon dioxide gas produced is much greater than the volume of the cylinder and therefore the gas exerts pressure on the water and drives it out with great force.

The fire is extinguished, partly by the water, and partly by the gas. It seems strange to speak of putting out a fire by means of gas, but carbon dioxide gas has three properties which make it very valuable for this purpose: first, it does not burn; second, it does not support combustion, that is, it does not help other things to burn; third, it is heavier than air. The carbon dioxide gas surrounds the fire and smothers it, because it does not support combustion and it takes the place of the air which does support combustion.

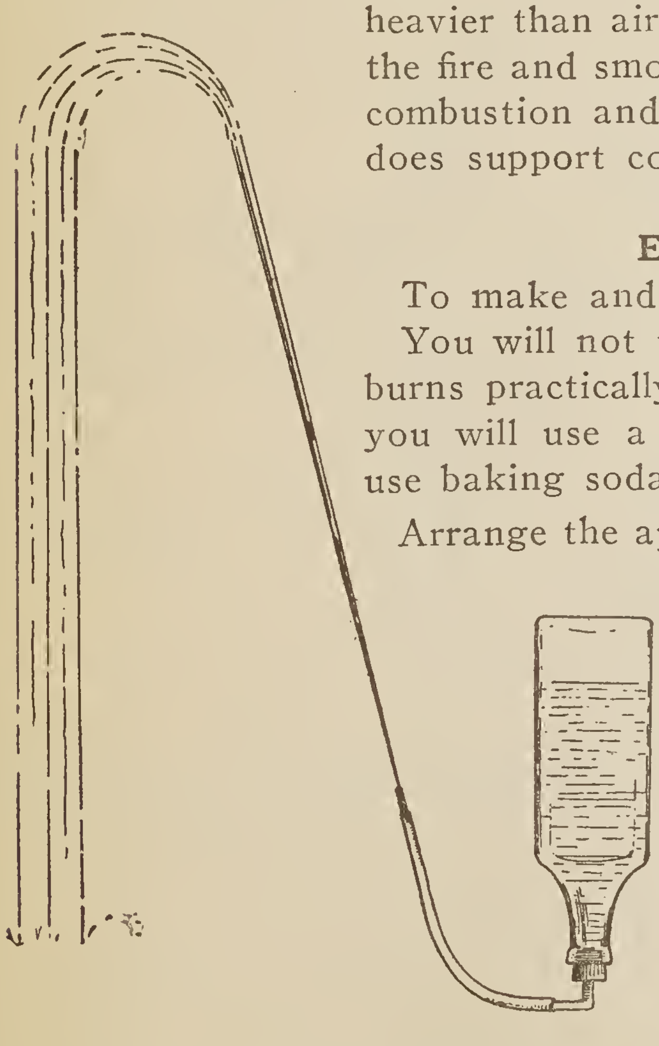


Fig. 161.—A Home-Made Fire-Extinguisher in Action

EXPERIMENT No. 62

To make and operate a fire extinguisher.

You will not use strong sulphuric acid because it burns practically everything it touches, but instead you will use a dilute acid, vinegar; also you will use baking soda which is sodium carbonate.

Arrange the apparatus as shown in Fig. 161. Pour six tablespoonsful of vinegar into the bottle, fill the bottle four fifths full of water and shake, measure out one level tablespoonful of baking soda and place it on a piece of paper ready for use.

Now to use the fire extinguisher, **go outside** and let one experimenter hold the bottle and stopper while the other holds the baking soda and the nozzle. Dump the soda into the bottle, put in the stopper quickly and hold it very

firmly, turn the bottle upside down and shake. Does the gas drive the water out with considerable force?

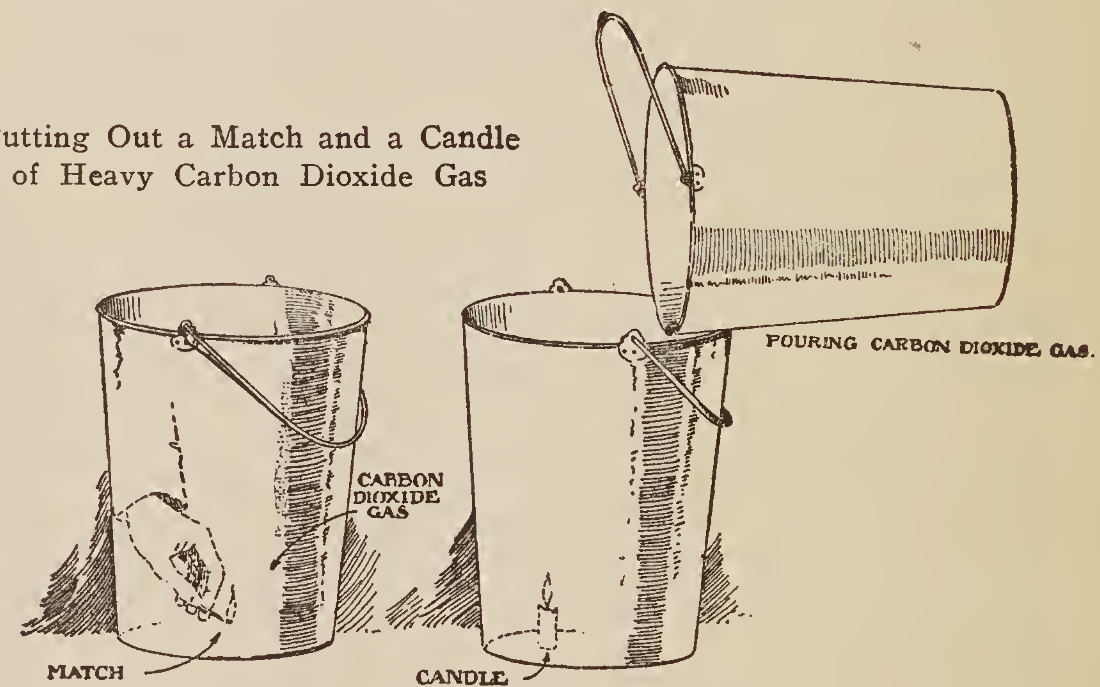
Repeat the experiment but this time make a cigarette shaped tissue paper package of the baking soda and attach the open end to the underside of the stopper by means of a pin. The extinguisher then will work when you turn it upside down.

Repeat but use the white and blue packages of a Seidlitz powder instead of the vinegar and soda. Dissolve the contents of the blue package in the water and dump in the contents of the white. They produce carbon dioxide gas.

EXPERIMENT No. 63

To show how carbon dioxide gas puts out a fire.

Fig. 162.—Putting Out a Match and a Candle by means of Heavy Carbon Dioxide Gas



You can show that the carbon dioxide gas (CO_2) is heavy and that it will put out a fire as follows: Pour six tablespoonsful of vinegar into an empty ten-quart pail, Fig. 162, and add one level tablespoonful of baking soda. Stir with a spoon until the fizzing stops. You now have the bottom of the pail full of carbon dioxide gas. You cannot see it but it is there. Now light a match and lower it slowly into the pail.

Does it go out when it gets a certain distance into the pail? It goes out because it is surrounded by carbon dioxide gas which does not support combustion.

Light a candle and lower it into the pail in the same way. Does it go out? It goes out for the reason stated above.

You know that (CO_2) gas is heavier than air because it remains in the bottom of the pail. If it were lighter, the air would sink to the bottom of the pail and lift it out.

You can show that the (CO_2) gas is heavy and that it will pour just like water, as follows: Put a lighted match or a very short lighted candle at the bottom of an empty pail, then lift the pail containing the CO_2 gas and pour it into the empty pail just as you would pour water.

Does the gas put out the match or candle? This shows that the gas pours and therefore that it is heavier than air. It also shows again that the CO_2 gas puts out a fire.

THE AIR PUMP

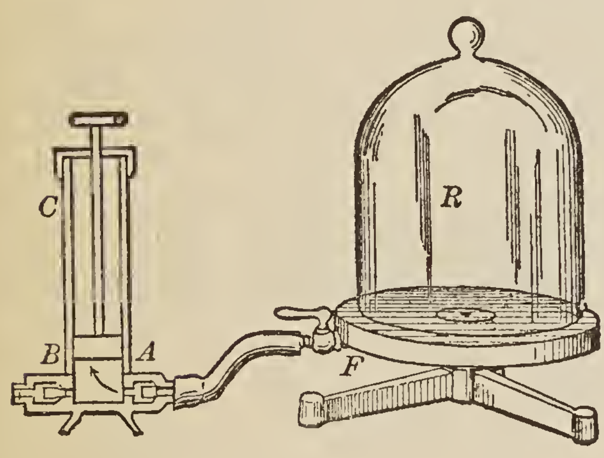


Fig. 163.—An Air Pump
Courtesy of the MacMillan Co.

The air pump shown here has a solid plunger and two valves A and B; valve A opens inward and valve B outward. The vessel R, out of which the air is being pumped, has an open bottom with a ground edge which fits air-tight on the smooth greased surface of the stand. The air is pumped out through a hole in the center of the stand and through the pipe F.

When the plunger is pulled up, valve B closes and part of the air **expands** from the vessel R through A into the pump cylinder C. When the plunger is forced down, valve A closes and the air in C is forced out through the valve B.

When the plunger is again raised part of the air remaining in R **expands** into C and when the plunger is forced down this air is forced out through B, and so on.

If you wish to pump air **into** R you attach it to B instead of to A and operate the plunger. Each stroke of the plunger fills the cylinder C with air and each down stroke forces this air into R.

EXPERIMENT No. 64

To make and operate an air pump.

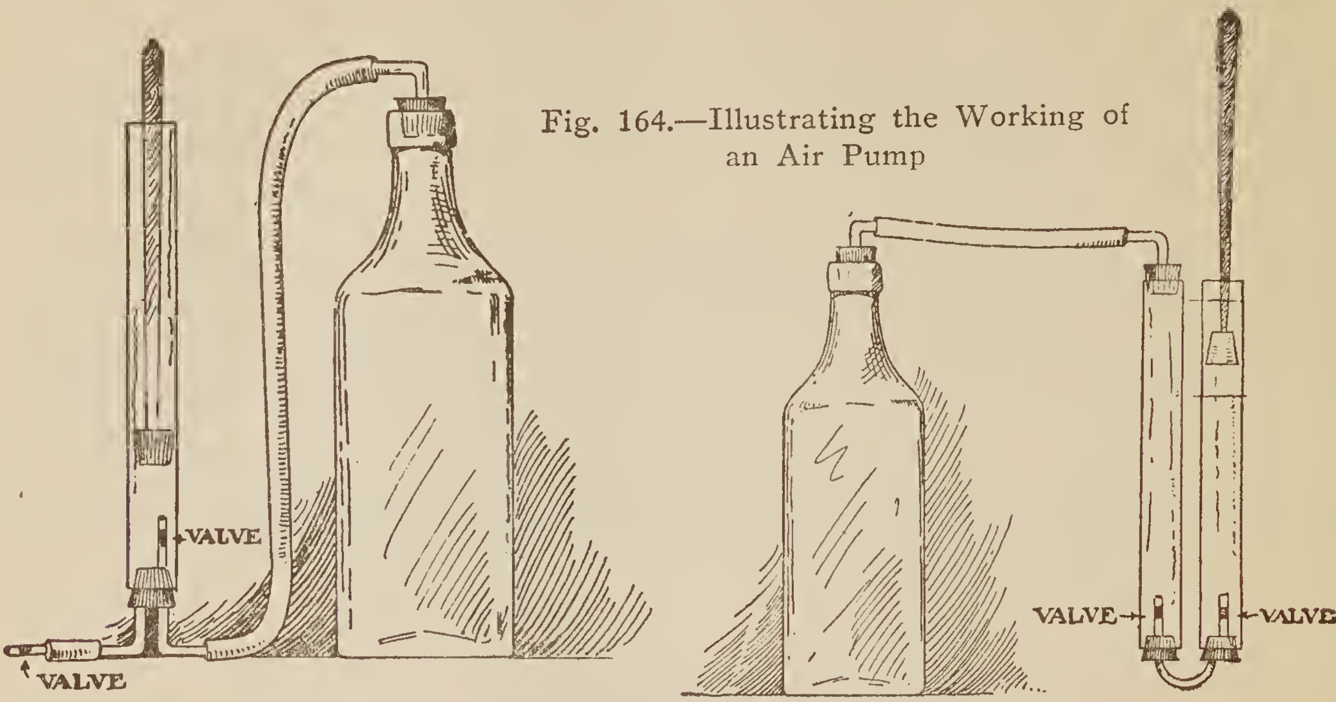


Fig. 164.—Illustrating the Working of an Air Pump

Arrange the apparatus as in (1) Fig. 164 and operate the plunger. Do you pump air **out** of the bottle?

Arrange the apparatus as in (2) Fig. 164 and operate the plunger. Do you pump air **into** the bottle?

THE BICYCLE PUMP AND TIRE

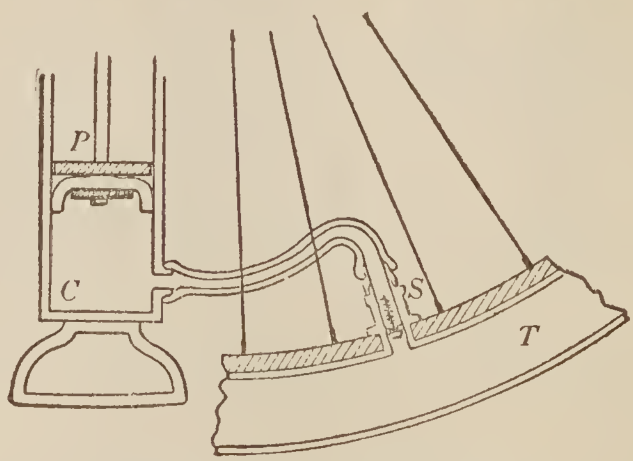


Fig. 165.—The Bicycle Pump
Courtesy of the MacMillan Co.

The bicycle pump is a very simple air pump. It consists of a cylinder C and a plunger P; one valve is the cup shaped piece of leather on the bottom of the plunger, and the other is the valve S which remains on the bicycle tire, T.

When the plunger is moved up there is a vacuum left in the space C beneath, and the pressure of the atmosphere forces air into this space around the sides of the cup valve which bends in. When the plunger is forced down, the air in C is forced into the tire through the valve S, because the cup leather is forced outward by the air pressure and becomes air-tight. This is repeated at each stroke.

The hand pump, at the right has a hollow plunger stem through which the air passes to the tire. A cup leather on the plunger is one valve and the valve on the tire, the other.

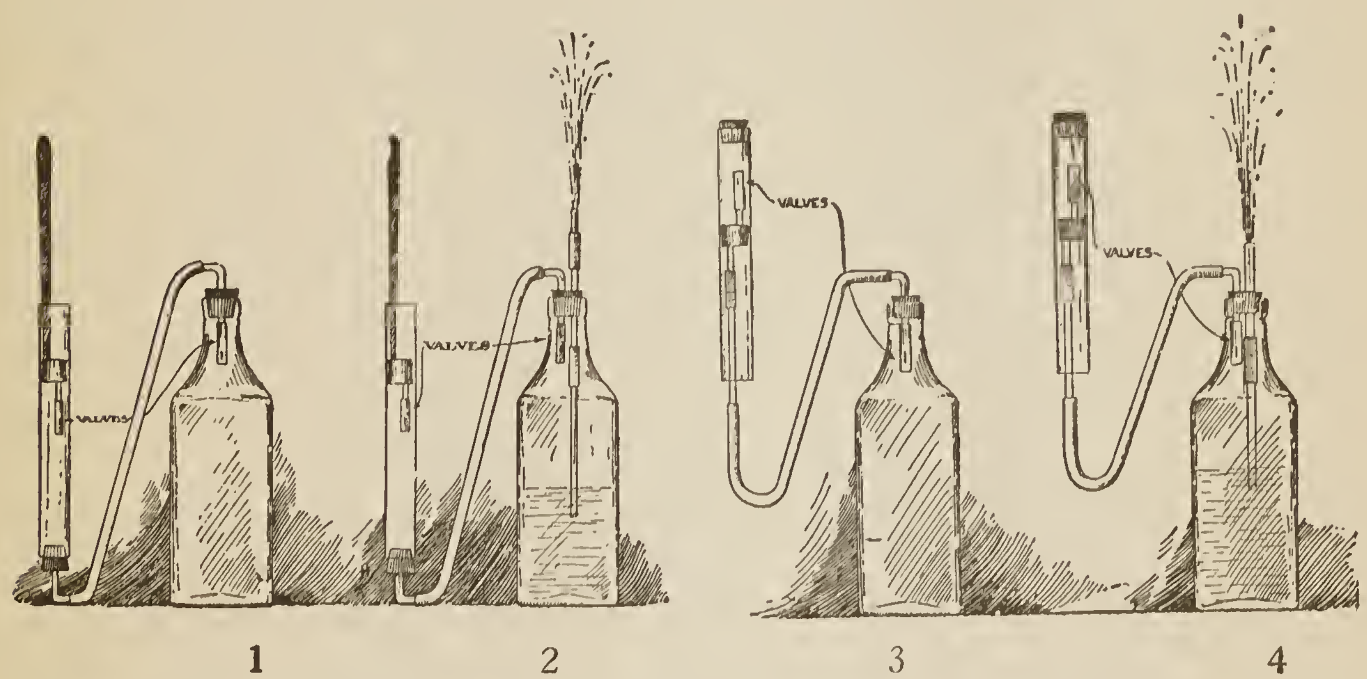


Fig. 166.— The Bicycle Pump in Action

EXPERIMENT No. 65

To make and operate two bicycle pumps.

Arrange the apparatus as in (1) and operate the plunger. The bottle with its valve represents the bicycle tire with its valve. Do you pump air into the tire?

Arrange the bottle as in (2) and pump air into it. Does the compressed air force the water out?

The above represents the action of a large bicycle pump.

Make the experiments (3) and (4). The pump here represents a hand bicycle pump.

THE AIR COMPRESSOR

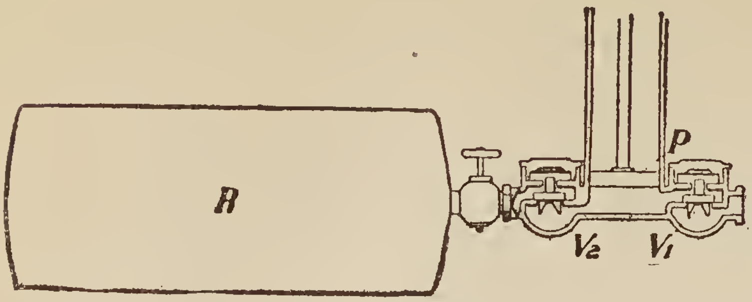


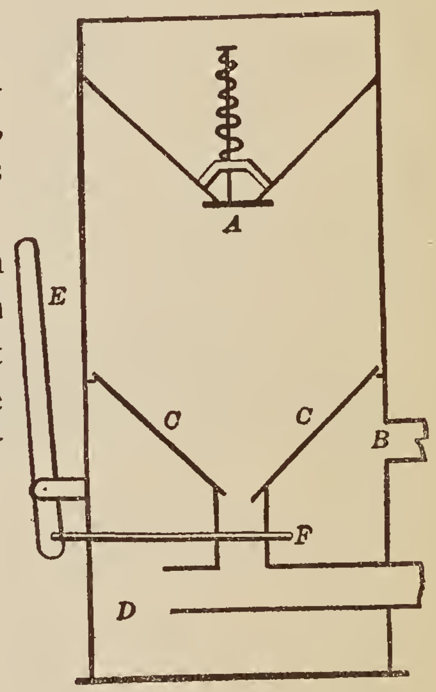
Fig. 167.—Air Compressor Pump and Storage Tank
From the "Ontario High School Physics"
By Permission of the Publishers

The commercial air compressor is simply a large air pump as shown in Fig. 167. It has a solid plunger P and two valves. When the plunger is raised, the pressure of the atmosphere lifts valve V_1 and forces air into the pump barrel; when the plunger is driven down, valve V_1 closes but valve V_2 opens and the air is forced into the storage tank R. This operation is repeated at each stroke. The pump is driven by a steam engine, gasoline engine, electric motor, or water wheel.

THE SAND BLAST

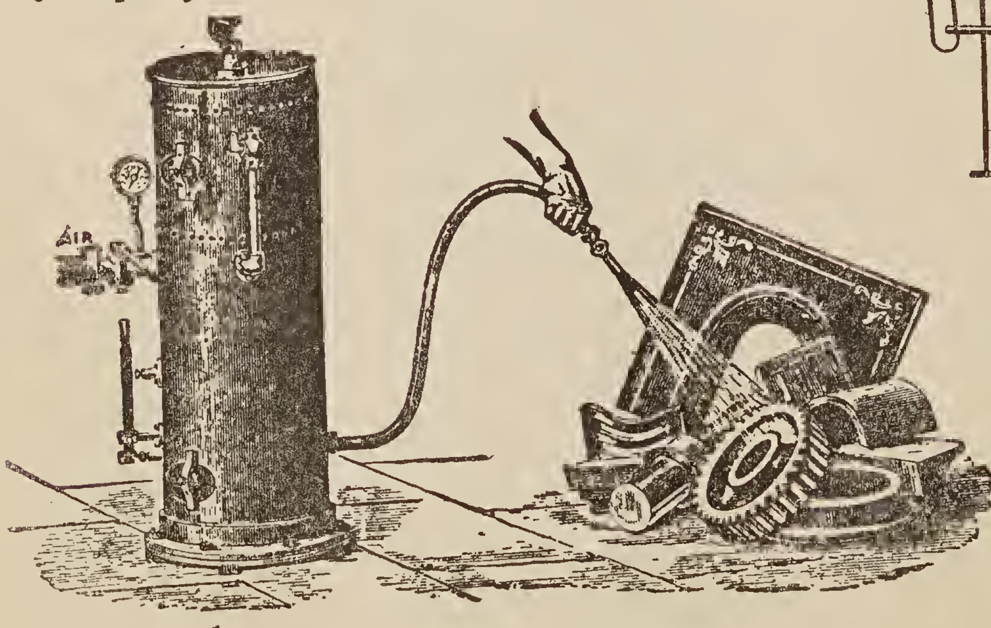
The sand blast, one form of which is illustrated in (1) Fig. 168, is used to clean metal castings, etch glass, cut the letters in marble, clean the walls of buildings, and so on.

The sand is driven by compressed air with great force against the object to be cleaned. Each particle of sand pulverizes the material which it strikes and since millions of grains strike the material each minute, the surface is worn away very rapidly.



2

Fig. 168.—Interior of a Sand Blast.
From "Hitchcock's Compressed Air and Its Apolications"
Courtesy of the Norman W. Henley Publishing Co.



1 Fig. 168.—A Sand Blast

The inside of the machine is represented in (2) Fig. 168. The sand is dumped into the V shaped top and is admitted to the chamber CC below through the valve A. The compressed air enters at B and passes out to the hose and nozzle through the tube D. The sand is dropped into the moving air through the valve F and is carried through the hose and nozzle to the object.

EXPERIMENT No. 66

To make and operate a sand blast.

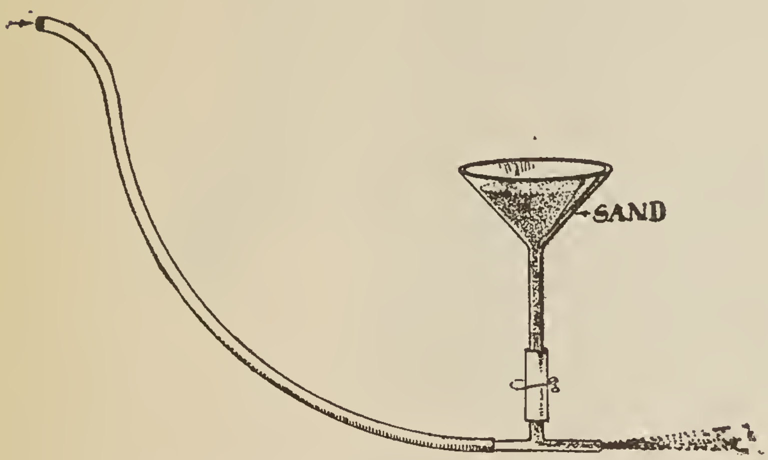


Fig. 169.—Illustrating the Working of a Sand Blast

Arrange the apparatus as shown in Fig. 169. The sand is held in the funnel and drops down into the moving air when the clip is opened.

Fill the funnel with dry, coarse sand and ask your partner to hold his hand over the funnel and open the clip, while you blow air into the hose and hold your hand opposite the tee opening to feel the effect.

Your partner's hand must be held over the funnel, otherwise part of the air will blow up through the sand.

Repeat this with the bottle used as a compressed air tank. Pump air into the tank by means of a bicycle pump, and close the hose with a clip. Connect the hose with the tee, ask your partner to hold his hand over the funnel and open the funnel clip, then hold your hand in front of the tee opening, and open the clip on the hose.

Do you find that the sand strikes your hand with considerable force?

PNEUMATIC PAINT BRUSH

The working of the pneumatic paint brush is as follows: The compressed air enters through the hose and handle and issues from a small nozzle. The current of air thus produced carries out with it the air around the nozzle and creates a partial vacuum. The atmospheric pressure on the paint in the tank then forces paint into the vacuum around the nozzle, and this paint is carried out through the large nozzle by the air current. The air pressure is from 50 to 80 lbs. per sq. in. and the stream of paint can be regulated from a fine mist to a solid stream.

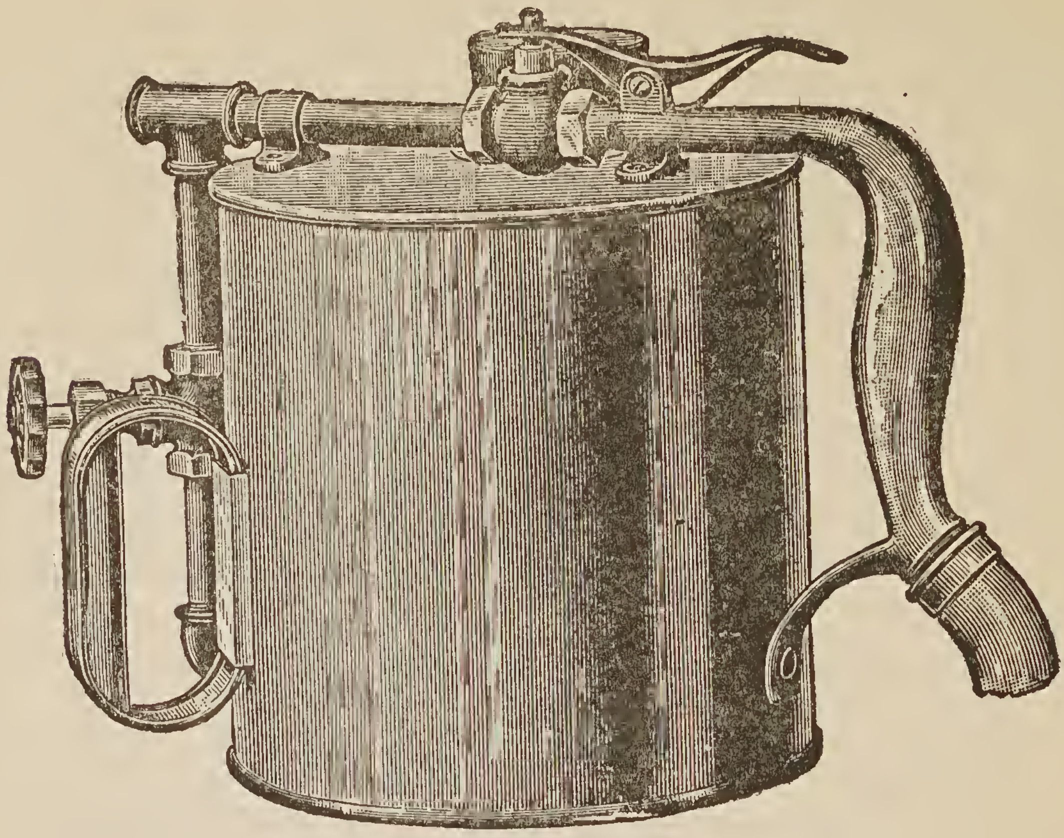
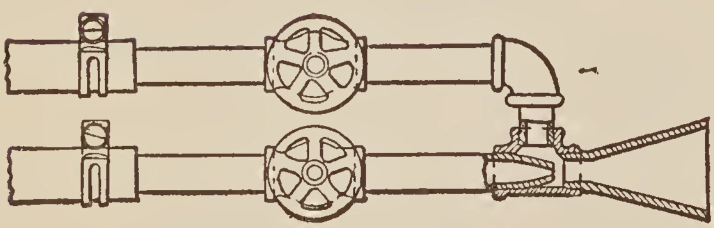


Fig. 170.—A Pneumatic Paint Brush



Paint Nozzle

From "Hitchcock's Compressed Air and Its Applications" Courtesy of the Norman W. Henley Publishing **Co.**

This form of paint brush is used in all kinds of painting and permits very rapid work. It is used in painting buildings, bridges, machinery, railway cars, furniture and even pictures, also in calsomining and white-washing walls, houses and fences, and in spraying disinfectants in hospitals, camps, trenches, hen houses, etc. The common atomizer is made on the same principle.

EXPERIMENT No. 67

To make and operate a pneumatic paint brush.

Arrange the apparatus as in Fig. 171 and blow hard into the rubber tube.

Do you observe that water rises from the tumbler into the wide tube, and issues from the narrow tube in the form of a light spray?

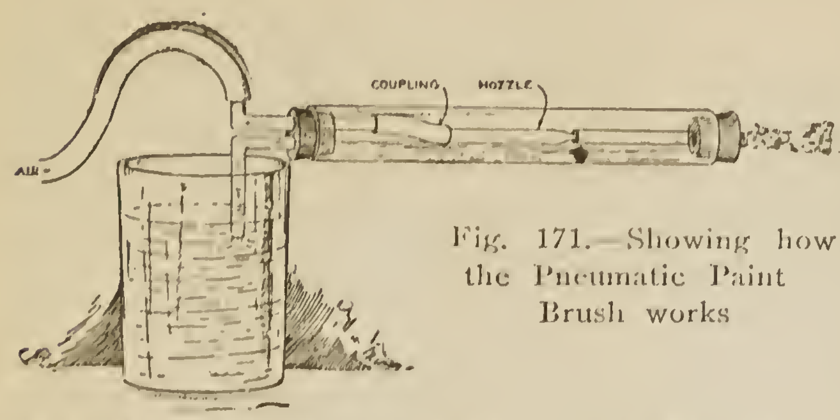


Fig. 171.—Showing how the Pneumatic Paint Brush works

This is very interesting, because it shows that although you blow air into the wide tube you create a partial vacuum in the tube. The reason for this is as follows: The compressed air from the nozzle enters the narrow tube with great velocity and in doing so carries air from the wide tube along with it. This creates a partial vacuum in the wide tube and the pressure of the atmosphere lifts water from the tumbler into the wide tube. The water is then carried into the narrow tube by the stream of compressed air and issues from the end.

THE DIVING BELL

The diving bell, Fig. 172, is simply a large iron bell open at the bottom. It is used to enable men to work on the bottom of a river, lake, or ocean, for example, to lay the foundations of bridges, wharves, lighthouses, etc.

The bell is made large enough to hold a number of men, heavy enough to sink readily in the water, and strong enough to stand the great pressure of the water on the outside. It is usually carried in a ship in a special compartment called a well: this is simply a hole in the bottom of the ship, lined up on all sides to prevent water from entering the ship. The bell is raised and lowered by means of a winch and pulleys, and is supplied with compressed air through a strong rubber tube attached to an air pump on the ship.

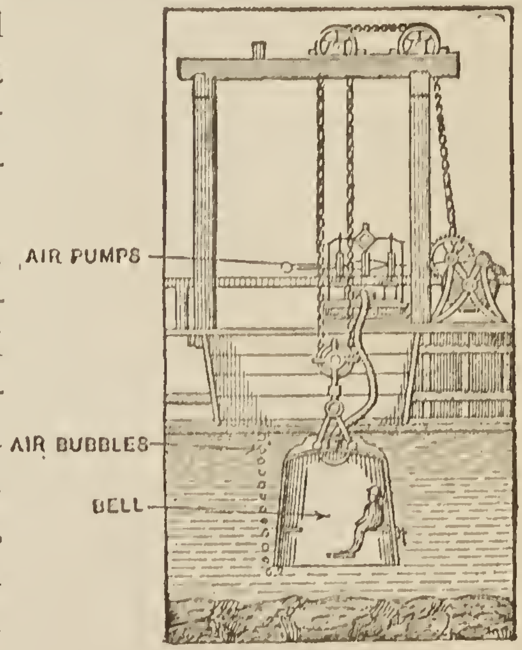


Fig. 172. A Diving Bell used to Work under Water
Courtesy of the MacMillan Co.

When it is desired to use the diving bell, the sailors first anchor the ship fore and aft over the spot where the work is to be done, then the workmen get into the bell through the bottom, the air pump is started, and the bell is lowered by means of the winch and pulleys.

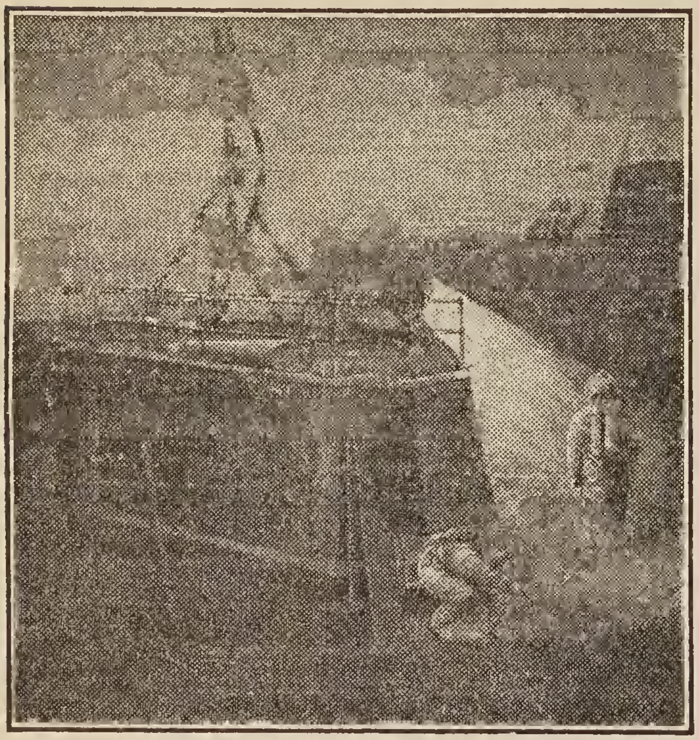


Fig. 173.—A Large Diving Bell used as an Undersea Storehouse by Divers
Courtesy of the Scientific American

The compressed air which is forced into the bell supplies the men with fresh air and also prevents the water from entering the bottom of the bell; the excess air escapes in bubbles under the edge of the bell.

A form of diving bell used by divers is illustrated in Fig. 173. It is lowered by a heavy cable from a ship at the surface, from which it is supplied with compressed air, electricity, and telephone connection. The diver carries his air in a tank on his back and is therefore not encumbered by a heavy air hose; the light cable which he drags is his telephone connection. The bell serves as a store house for tools and as a place to which the diver can retreat to repair his suit if necessary. He enters and leaves the bell through an opening near the bottom as shown.

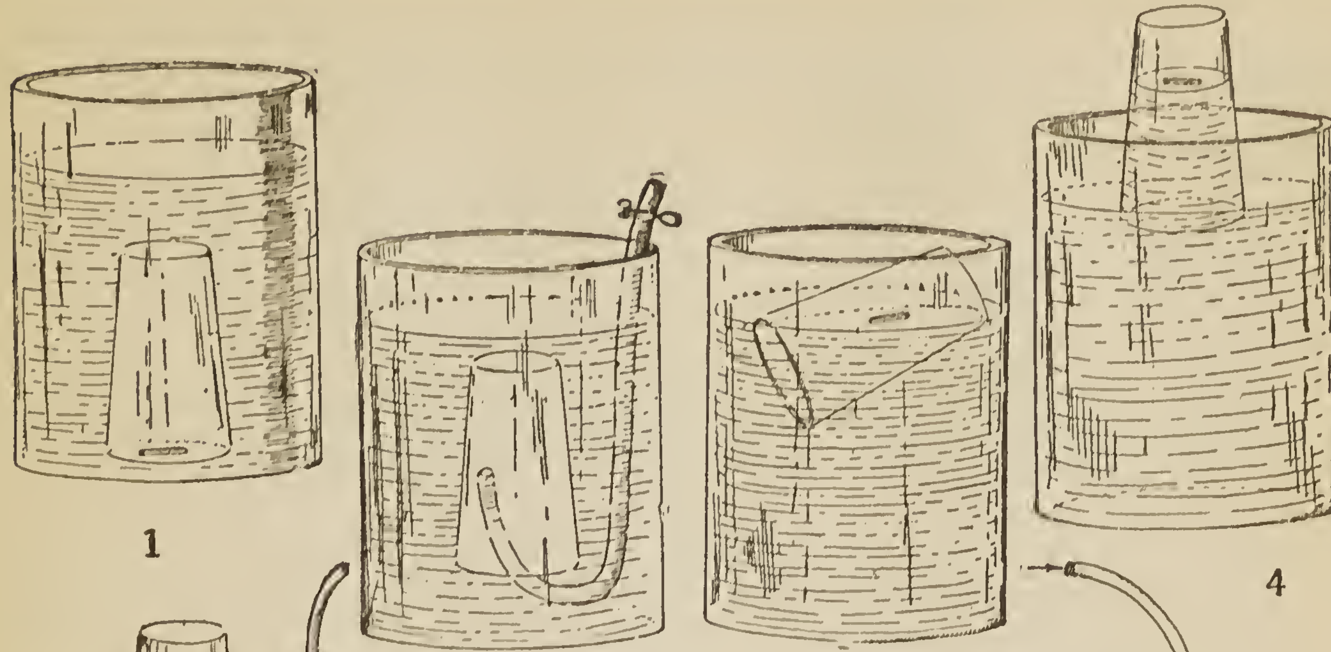
EXPERIMENT No. 68

To make and operate a diving bell.

Place a piece of a match stick on the surface of the water in a wash bowl. Invert an empty tumbler over the match and force the tumbler to the bottom of the bowl without letting air escape. Do you notice that the water enters the tumbler only to a very sligh extent and that you can make the match rest on the bottom of the bowl.

The tumbler represents the diving bell and the match stick represents the man, who could now go to work on the bottom of the river or lake. Of course, the man in a regular diving bell would not get into the water first but would stand or sit on a shelf inside the bell. Raise the tumbler gradually and notice that the water lifts the match up again.

In this experiment the lower edge of the diving bell, the tumbler, is only six or eight inches under the surface of the water, therefore the



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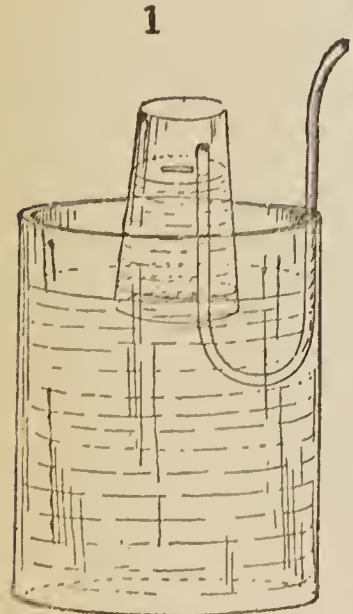


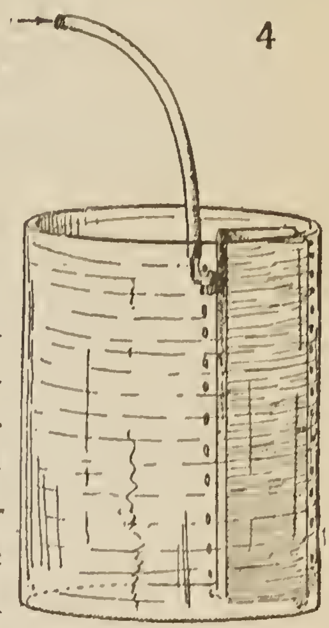


Fig. 174.—Illustrating the Working of the Diving Bell

5 6

pressure of the water upward on the air in the bell is small, and the air is only slightly compressed. When the regular diving bell is sunk in water, however, the pressure of the water upward on the air in the bell increases as the bell sinks deeper and deeper and the water would rise in the bell, were it not that the compressed air is pumped in at sufficient pressure to overcome this water pressure and to keep the water out.

Repeat the experiment with the hose as in (2). Open the hose. Is the air forced out? Blow air into the hose. Is the water forced out?

Lift a boat above the water level as in (3), (4) and (5). Make the experiment with the metal tank used as the diving bell (6).

EXPERIMENT No. 69

To make a home-made diving bell.

You can have fun in your swimming pool by using either a 12 qt. pail, a wash boiler, or a wash tub, as a diving bell. Do this as follows:

Place the inverted pail over your head and let yourself sink. You will find that you can breath under the pail for a short time but that the

air soon needs renewing. You will find also that you cannot sink very far, because the buoyancy of the inverted pail is greater than the weight of your body in water.

Fig. 175.—A Small Home-Made Diving Bell

Repeat the experiment with a wash boiler or wash tub. You will find again that you can breath under the boiler or tub. You will find also that you cannot sink the boiler or tub because their buoyancy, when inverted and filled with air, is much greater than the weight of your body in water.

Make this experiment. Go to a part of the swimming pool where you can sit on the bottom with your head above water, then let two of your friends place the tub, upside down and full of air, over your head and force it down gently until the bottom of the tub is slightly under the surface. Your head is now below the level of the water outside, but you will find that you have plenty of air in the tub because the water level in the tub is only slightly above the level of the edge of the tub.

Make experiments of your own.

PNEUMATIC CAISSONS

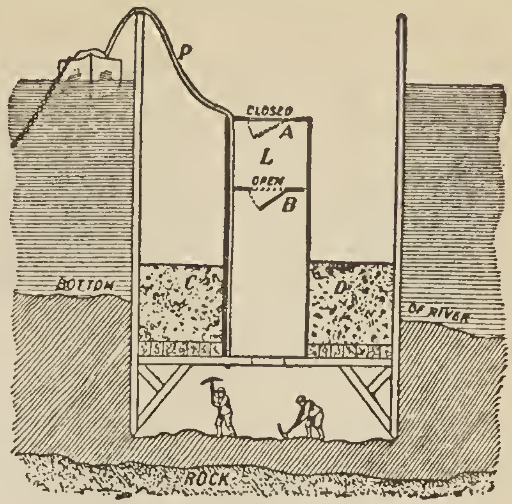
A caisson similar to that shown here is used to remove the earth down to the rock for the foundations of bridge piers. It is filled with compressed air which drives the water out at the bottom and leaves the earth dry for the workmen.

The caisson is closed in on all sides to keep out the water. It is open at the bottom but is closed above by well braced timbers weighted down by concrete C.D. The bottom is let down into the mud, the compressed air is turned on to force the water out of the working chamber, and the workmen then enter the working chamber to excavate the mud. The weight of the concrete C.D. gradually sinks the caisson, as the mud is excavated, until the solid rock is reached.

The men enter the caisson through the air lock L, as follows: The lower door B is closed, compressed air is let out of L, the door A is

opened, the workmen enter, the door A is closed and compressed air is admitted slowly to L until its pressure is equal to that below; the door B is then opened and the men climb down a ladder into the caisson. The men leave, and mud is lifted out through the air-lock by the reverse proceedure.

When the caisson is down to the rock, the working chamber and the space above are filled with concrete to serve as the foundation of the bridge. Sometimes the outer casing of the caisson is removed, but more often it is left where it is.



—Section of a Pneumatic Caisson. The sides of the caisson are extended upward and are strongly braced to keep back the water. Masonry or concrete, *C*, *D*, placed on top of the caisson, press it down upon the bottom, while compressed air, forced through a pipe *P*, drives the water out of the working chamber. To leave the caisson the workman climbs up and passes through the open door *B* into the air-lock *L*. The door *B* is then closed and the air is allowed to escape from *L* until it is at atmospheric pressure. Then door *A* is opened. In order to enter, this process is reversed. Material is hoisted out in the same way or is sucked out by a mud pump. As the earth is removed the caisson sinks until the rock is reached. The entire caisson is then filled with solid concrete, and a permanent foundation for a dock or bridge is thus obtained.

Fig. 176

From the "Ontario High School Physics", By Permission of the Publishers

EXPERIMENT No. 70

To make and operate a pneumatic caisson and to show how a man enters it through the air-lock.

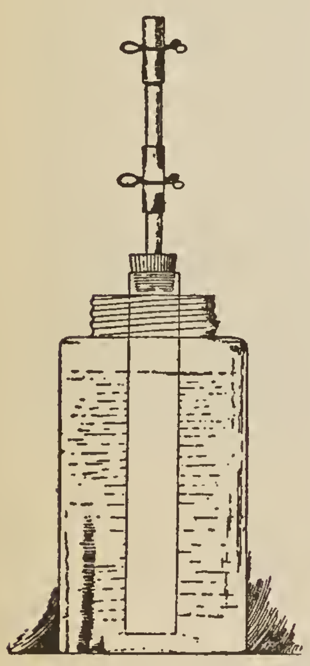


Fig. 177.—Illustrating the Working of a Pneumatic Caisson

Arrange the apparatus as shown in Fig. 177. The wide tube represents the caisson and the narrow tube at the top, the air-lock; the clips represent the upper and lower doors of the air-lock.

Put the caisson, with both clips open, in the sealer full of water.

Do you find that the water level inside the caisson is the same as that outside?

Now blow air in through the air lock and close one or both clips.

Do you find that the water level inside the caisson is now at the bottom?

This illustrates the manner in which compressed air forces the water out at the bottom of a real caisson.

Now to show how a man enters the caisson without letting out the compressed air, proceed as follows:

Use a pin to represent the man, be sure that both doors are closed, then open the upper door and drop the pin into the air-lock head downwards, not that the

man enters head downwards, but the head of the pin will not stick into the rubber as the point might.

Now open the lower door.

Does the pin drop to the bottom and has the whole operation been completed without letting air out of the caisson or water into it.

This represents the way a man would enter the caisson. It is called "locking in". The man of course would not drop from the air lock to the bottom of the caisson; he would climb down a ladder. Tools and materials are admitted to the caisson in the same way, and removed by reverse operation.

EXPERIMENT No. 71

To show how a torpedo is shot out of a submarine or battle ship.

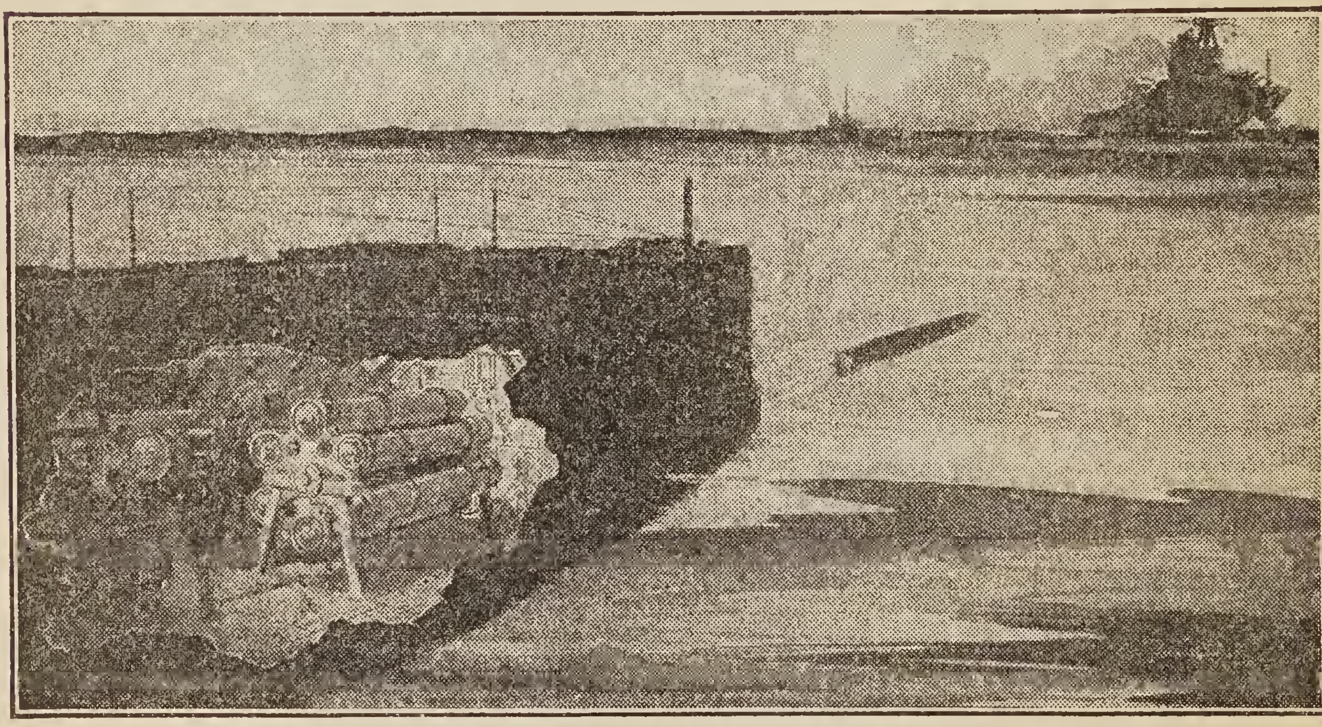
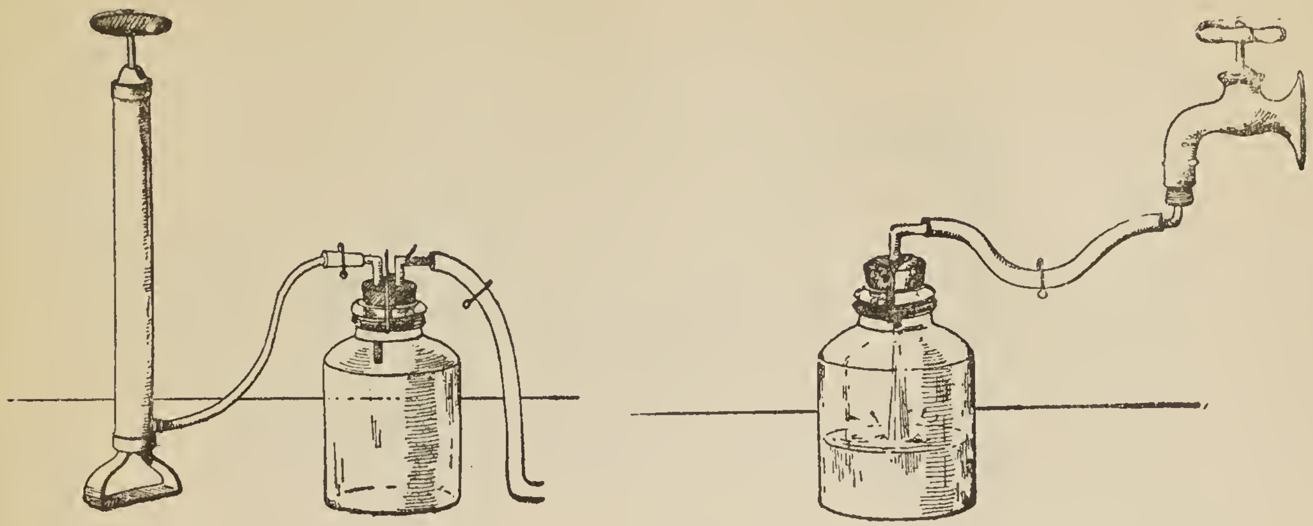


Fig. 178.—The Revolver Torpedo Tube in Submarines

By carrying the torpedoes in a revolving cradle back of the torpedo tube, it is possible to fire several torpedoes in rapid succession while the submarine is bearing on the enemy

A torpedo is fired out of a submarine or battle ship by means of compressed air and is kept in motion after it is fired by means of a compressed air motor.

Show how the torpedo is fired, by means of the apparatus Fig. 179. The bottle here represents the compressed air tanks on the battleship, the wide tube represents the torpedo tube and the plunger, the torpedo.



1 2

Fig. 179.—Showing How a Ship is Torpedoed

3

Close the bottle by means of cord and rubber bands and compress air in it by means of a bicycle pump (1) if you have one; if not, attach the rubber tube to a water faucet by means of an elbow and stopper (2) and fill the bottle half full of water in order to compress the air to half its first volume and thereby give it a pressure of 15 ℔s. per sq. in. Connect the bottle with the torpedo tube, point the tube at the ship (3) and open the clip. Do you torpedo the ship in a very realistic manner

EXPERIMENT No. 72

To show how the men in a submarine could be supplied with air taken from sea water.

Arrange the apparatus as in (1) Fig. 180. The space between the stoppers is completely filled with water and is free from air; the plunger is covered with water to make it air-tight.

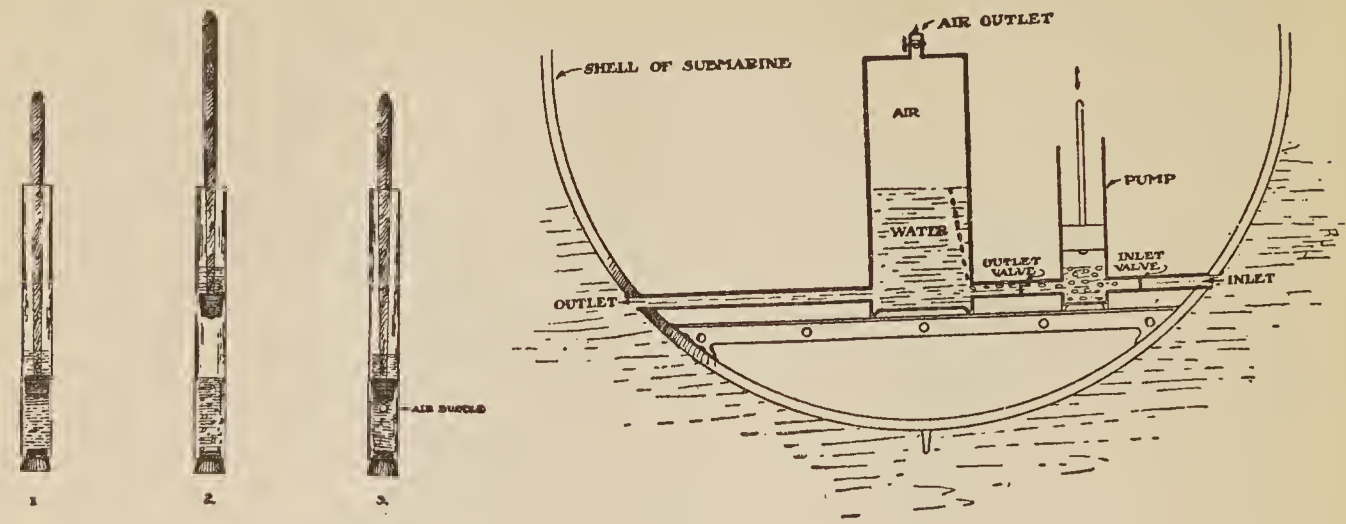


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Fig. 180.—Showing How a Submerged Submarine could take Air from Sea Water

Now lift the plunger as in (2). Do you observe that air bubbles come out of the water? Let the plunger go back (3). Do you observe that there is a small bubble of air between the rubber stoppers? This is extremely interesting and is explained as follows: All water on the earth which is exposed to the air has **air dissolved in it,** (the fish in water live on this air). When you lift the plunger you produce a vacuum above the water and thereby reduce the pressure on the water to zero. The air in the water then expands into bubbles and escapes from the water.

Submarines could be supplied with pure air when under water as follows: They would need a pump similar to your apparatus above but arranged as follows: During the upstroke of the plunger the inlet valve would open for say only ¼ of the stroke and then close for the remaining ¾ of the stroke. The plunger would thus draw in water during ¼ stroke, and would produce a vacuum above the water for the remaining ¾ stroke, the air in the water would then expand and escape from the water.

On the down stroke of the plunger the air and water would be forced out of the pump but on their way out of the submarine they would pass through a tank, the air would escape into the tank but the water would pass on out. The air accumulated in the tank could then be used in the submarine.

FINIS

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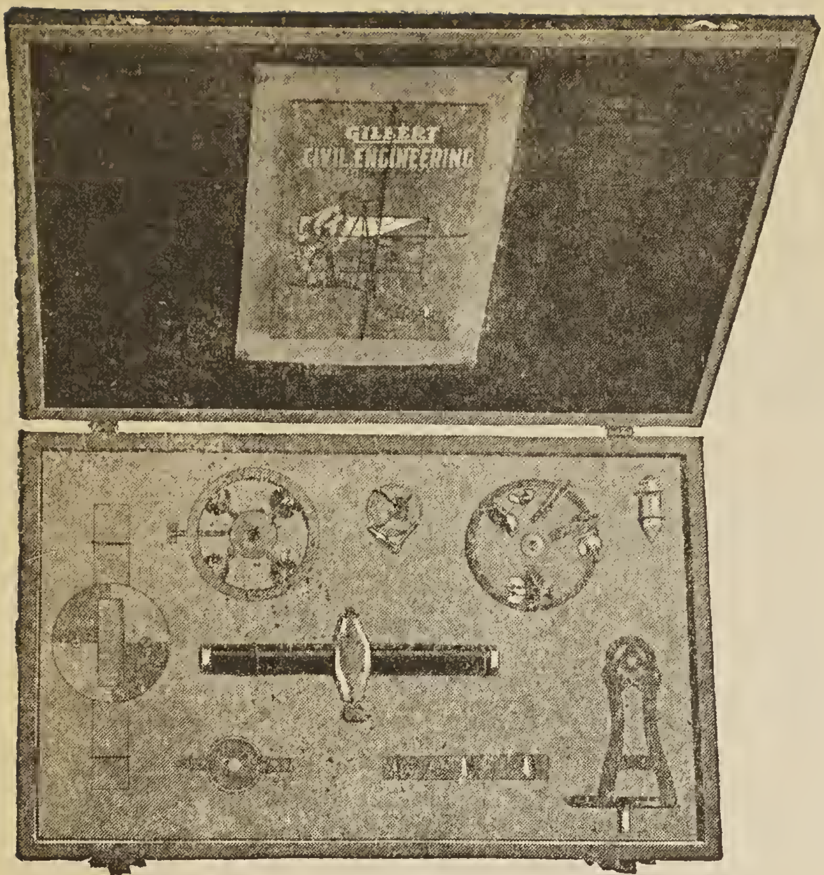
MEMORANDUM

MEMORANDUM

MEMORANDUM



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